STEAM TURBINE ENGINEERING

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STEVENS AND HOBART

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WITH 516 ILLUSTRATIONS

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PREFACE

NOTWITHSTANDING the treatises on the Steam Turbine which have already been published, there is still a distinct field heretofore not covered. This relates to a consideration of the subject from the standpoint of the purchaser and user. While the purchaser is only incidentally interested in the theory and design of the steam turbine, he is deeply concerned as to the question of its economy as regards not only steam consumption but also first cost and maintenance. It is, moreover, to him of great importance to be in a position to estimate the relative total costs and economy of complete projects in which, on the one hand, steam turbines, and, on the other hand, other types of prime mover are employed.

Manufacturers and Designers become so absorbed in their respective occupations that they are apt to lose sight of, or not have time to investigate, some aspects of the subject. Thus, to them also, we believe, our work may prove of service.

The authors wish to embrace this opportunity of making due acknowledgment of the assistance rendered them by designers, manufacturers, and users.

In the former class should be mentioned Professor Rateau, Directors Zoelly and O. Lasche, M. Sosnowski, Mr F. Samuelson, Mr Wm. Gray, Mr August Kruesi, and Mr Konrad Andersson.

The list of Manufacturers who have placed data at our disposal includes :—The Société de Laval of France; Messrs Greenwood & Batley, Leeds; The de Laval Steam Turbine Co., Trenton, N.J.; The Maschinenbau-Anstalt Humboldt, Kalk, near Cologne; Messrs Brown-Boveri & Co.; The Brush Electrical Engineering Co., Ltd.; Willans & Robinson, Ltd.; Messrs C. A. Parsons & Co.; The Westinghouse Cos. of Pittsburg and Manchester; The General Electric Co. of America; The British Thomson-Houston Co.; Messrs Belliss & Morcom; Messrs Bumstead & Chandler; Messrs Browett, Lindley & Co.; Messrs Howden; Messrs Van der

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In supplying us data regarding plants employing steam turbines, and also (in order to obtain comparisons) regarding piston-engine plants, we are indebted to the courtesy of—

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Mr John R. Hewett very kindly collected the General Electric Co.'s (of New York) data for us, and visited four Curtis plants to gather further details; and Mr Eustace Down very kindly collected data on the Neasden plant, with permission of the Consulting Engineer.

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STEAM TURBINE ENGINEERING

CHAPTER I

INTRODUCTORY

EXCELLENT steam economy is now obtainable by the steam turbine when operated condensing, and improved manufacturing methods, stimulated by competition, are slowly reducing the first cost. Great initial savings in foundations, and in consequence of the small floor space required, are also sometimes effected by employing steam turbines. The oil consumption is very low; and as no oil is present in the cylinders, there being no parts there requiring lubrication, not only does the condensation become directly available for feed water, but there is the further advantage that high superheat introduces no difficulties relating to choice of lubricant. In sets of large capacity the steam turbine offers advantages in all these respects. In small sets the steam economy is none too good, but the other advantages will, nevertheless, often justify its use in preference to the piston engine.

Against these advantages must be set the great sacrifice in economy when, through any cause, a plant must be temporarily operated non-condensing; also the greater outlay entailed for condensing plant, owing to the supreme importance which the degree of vacuum has upon the turbine's economy. It is probable that, with the better understanding of the methods of employing superheated steam, a given degree of superheat will ensure a greater percentage improvement in the steam economy in the piston engine than in the steam turbine. This, however,

depends somewhat upon the type of steam turbine; as does also the economy at light loads, with respect to which it may be safely asserted that the piston engine is not excelled by the steam turbine, as has been so often incorrectly stated. In fact, the marvellously rapid progress which has recently taken place in the development of the steam turbine has already reacted to stimulate the designers and manufacturers of piston engines, and marked improvements are again becoming very evident in this class of steam engine.

High speed—the very feature which has led to the small size, weight, and (to a less degree) cost of the steam turbine—has also brought with it disadvantages, especially as regards the design of direct-connected electric generators; and the present tendency is to reduce the speeds, as far as considerations of steam economy permit. It would probably be good practice, in spite of increased size, to work at speeds well below this point, since a slight sacrifice in steam economy would be more than offset by the far more satisfactory results, not only in the design of the electrical apparatus, but also in the mechanical design of the turbine itself. There is thus a large array of considerations requiring detailed discussion.

Parsons and de Laval were the pioneers in the development of the commercial steam turbine, and it requires no further justification that the description of their designs is given precedence in the following chapters.

In the immediately succeeding chapters are given descriptions of the turbines of the remaining leading types.

These descriptive chapters are followed by a recapitulation of the properties of steam, with new tables and curves to suit present requirements, and data tabulated for convenient comparison and reference on various electricity supply plants and marine steam turbines.

Cost.—As yet the steam turbine, as regards first cost, is somewhat more expensive than the piston engine. In a paper entitled *The Steam Turbine,*[1] Chilton gives £3250 as the "cost of prime mover and generator" for a 500 kilowatt set, whether of the piston-engine or turbine-driven type. This works out at £6, 5s. per rated kilowatt. Including condensing plant, the piston-engine plant is increased to £7, 6s. per kilowatt, as against £7, 8s. per kilowatt for the turbine plant.

[1] *Proc. Inst. Elec. Engrs.*, vol. 33, pp. 587–601, Feb. 2, 1904.

Other accessible cost data is as follows:—

TABLE IA.

Purchaser.	Date.	Tenderer.	£ per rated K.W.	£ per Ton.		Number of Units.	Rated Output.
[1] Whitby U.D.C.	Ordered 1905	Parsons	7·75		..	1	200 K.W.
[2] Keighley Corporation	Tender 1905	„	7·1		..	1	300 „
Southampton	..	„	6·66		Turbo-generator only	1	300 „
			1·87		Wheeler surface condenser, two motor-driven pumps	..	..
[3] Watford U.D.C.	Tender 1904	..	7·9		Includes exciter, condenser, air pump, circulating pump	1	500 „
[4] Derby	Ordered 1905	Parsons	7·8		..	1	500 „
Battersea	„ 1904	„	6·5		Turbo-generator and condenser plant and spare armature	1	750 „
	„ 1905	„	6·25		..	1	750 „

1 *Electrical Times*, 71, 12/1/05. 2 *Electrician*, 105, 5/5/05; *Electrician*, 6/8/04.
3 *Electrical Engineer*, 833, 27/5/04.
4 *Electrical Review*, 735, 5/5/05; *Electrical Engineer*, 349, 26/2/04; *Electrical Times*, 212, 9/2/05.

TABLE IB.—1900. CAMBRIDGE ELECTRICITY SUPPLY CO. TWO 500 K.W. SETS.

	Reciprocating Engines and Generators, excluding Condensers and Pumps.				Turbo-generator, including Condensers and Pumps.
Tenderer	*A*	*B*	*C*	*D*	Parsons
Steam-generator	8·4	11·2	10·	10·	..
Condenser, Pumps, Engine } about	2·1	2·1	2·1	2·1	..
£ per Rated K.W.	10·5	13·3	12·1	12·1	9·9
Steam Consumption:—					
25 per cent. overload	..	..	..	..	..
Lbs. per K.W.H.	..	..	25·5	..	..
Kgs. per K.W.H.	..	..	13	..	..
Full Load:—					
Lbs. per K.W.H.	28	28	27	26·6	27
Kgs. per K.W.H.	12·7	12·7	12·3	12·1	12·3
Half load:—					
Lbs. per K.W.H.	34	34	32	31·2	30
Kgs. per K.W.H.	15·5	15·5	14·6	14·2	13·7

Electric World and Engineer, March 31, 1900, p. 313.

Costs of some Turbo-Generators and Condenser Plants.—The prices that have appeared in the electrical press in the last eighteen months are included below with as much detail as practicable. Unfortunately, such information is generally published without specifically stating what is included.

Tenders for four sets, each 65 kilowatt, 110 volts, were discussed in *Marine Rundschau* for January 1904 in dealing with Professor Riedler's paper "Ueber Dampfturbinen." Reciprocating engines were ordered.

TABLE II.—PRICES OF 65 K.W. TURBO-DYNAMOS AND RECIPROCATING SETS.

Tenders.	Rated Output K.W.	Price per Rated K.W.		Price per Ton.	Steam Consumption per K.W. Hour.		Weight of Set per Rated K.W.	
		Marks.	£.		Kg.	Lbs.	Kgs.	Lbs.
Piston engine and dynamo	65	231	11·6	...	...	...	...	...
Riedler Stumpf. Turbo-dynamo	"	308	15·4	1340	17·1	37·6	11·5	25·4
Parsons Turbo-dynamo .	"	331	16·55	1440	18·8	41·4	...	...
Parsons "as it might have been if the turbine had been designed 0·5 metre longer (about 20 ins.)"	...	...	...	...	17·1	37·6	11·5	25·4

TABLE IIIA.

Purchaser.	Date.	Tenderer.	Price.	
[1] Greenock . .	Tender 1904	Brush-Parsons	£3,060	Rating not stated ; possibly 400 K.W.
		Parsons	3,000	Rating not stated.
[2] Hanley (Staff.) .	Tend'r 1904	Richardson	3,650	Rating not stated.
		Parsons	3,324	
		Bruce Peebles	3,234	
		Brush	2,840	
[3] St Marylebone .	Tender 1904	Parsons	79,598	Rating not stated. Apparently three 2000 K.W. with condensers and four 500 K.W. with 2 condensers. If assumption is correct, £9·95 per rated K.W. including condensers.
[4] Stepney . .	Ordered 1905	Parsons	5,900	Rating not stated.

[1] *Elec. Engr.*, p. 545, 1/4/04.
[2] *Elect. Rev.*, p. 144, 22/7/04.
[3] *Elec. Engr.*, p. 724, 6/5/04.
[4] *Electn.*, p. 647, 3/2/05.

TABLE IIIB.

Purchaser.	Date.	Tenderer.	Price per Rated K.W.	Price per Ton.		Number of Units.	Rated Output.
[1] Bristol Corporation . .	Ordered 1904	Willans-Parsons	..	..	..	2	1000 K.W.
[2] Leeds Corporation . .	,, 1904	Curtis B.T.H.	..	..	..	2	1000 ,,
[3] North Metr. E.P.S. Co., Willesden	,, 1905	Brush-Parsons	..	..	..	2	1000 ,,

[1] *Elec. Times*, 248, 18/8/04. [2] *Electrician*, 446, 30/12/04. [3] *Elec. Times*, 774, 25/5/05.

TABLE IV.

	£ per Rated K.W.			Condensing Plan .	£ per Ton.	Number of Units.	Rated K.W.	
	Reciprocating Engine.	Steam Turbine.	Generator.					
Rhenanian - Westphalian Electricity Works, Essen, by Brown-Boveri & Co., Mannheim, using 4 Kgs. per I.H.P. hour . . .	..	1·85	1·02	..	..	2	6500	*Power*, p. 407, July 1905.
A certain Reciprocating Set in America	4·1	..	2·24	..	..	..	5500	*Ibid.*
Vienna Sulzer Type, 4 cyl. triple expans., 90 revs., 245 tons	5	..	..	..	41	..	2000	*Lt. T. & Ry. J.*, 10/6/04.
Curtis Set erected . . .	..	5·6		0·6 to 0·8	.. 136	..	3000	Mr C. O. Mailloux, Am. S. R. A., 1904.

Tenders on 1000 Kilowatt and 1500 Kilowatt Sets.—The various tender prices (in £ and decimals) for the following places are tabulated. The accepted price is in bold type in each case.

TABLE V.—TURBO-GENERATORS.

Corporation.	Number.	Rated K.W. each.	Phases.	Cycles.	Volts.	R.P.M.	
Poplar . .	2	1000	3	50	6000	1500	Condenser plant and steam exciter.
Stepney . .	1	,,	Dbl. current	..	480 c.c.	..	Condenser plant and spare armature.
St Pancras .	2	,,	c.c.	..	..	..	Only one condenser plant and switchboard.
Norwich . .	1	,,	..	..	..	..	..
Wimbledon .	1	,,	1	50	2000	..	Condenser plant and exciter and switchgear.
Hammersmith	2	1500	2	..	2200	..	Condenser plant and exciter and switchgear.
Islington .	1	,,	..	..	..	..	Condenser plant and exciter and switchgear.

TABLE VI.—(*See Table V. for Ratings, etc.*)

	Turbine.	*Engine.*	Condenser.	1000 K.W. Units. Poplar.	1000 K.W. Units. Stepney.	1000 K.W. Units. St Pancras.	1000 K.W. Units. Norwich.	1000 K.W. Units. Wimbledon.	1500 K.W. Units. Hammersmith. Turbo-Alternator.	1500 K.W. Units. Hammersmith. Condensing Plant.	1500 K.W. Units. Hammersmith. Exciters.	1500 K.W. Units. Hammersmith. *Slow Speed Reciprocating Sets.*	1500 K.W. Units. Islington.
Data from / Page / Date	..	..	..	*E. Engr.* 544 1/4/04	*E. Engr.* 581 8/4/04	*E. Engr.* 725 6/5/04	*E. Times* 139 26/1/05	*E. Times* 207 10/8/05	*Electrical Review* 1/7/04				*E. Rev.* 184 4/8/05
B.T.H. Co.	Curtis	..	..	..	..	6·3	..	7·43	4·85	..	0·5	..	..
	"	..	..	..	..	..	..	..	..	0·7	..	..	..
	"	..	..	..	..	..	..	..	..	0·95	..	..	..
	"	..	..	..	..	..	..	..	..	1·05	..	..	..
	..	..	Mirrlees	..	..	..	..	..	..	..	..	..	7·1
	..	..	Allen	..	..	..	..	..	..	..	..	..	6·45
	..	..	Worthington	..	..	..	..	..	..	..	..	..	6·45
Bruce Peebles.	Parsons	..		6·7	8	..	..	..	4·25	0·8	0·3	..	6·5
	..	..	Mirrlees	..	..	..	..	7·72	..	..	..	..	..
	Rateau	..	"	..	..	..	..	8·49	..	..	..	..	..
	Richardson, W., & Co.	..	..	..	..	..	..	..	..	..	..	..	5·45
	Willans	..	..	..	7·2	..	..	..	..	..	..	..	..
Brush	..	..	..	..	7·85	..	..	7·72	5·	0·7	0·2	..	5·65
Dick Kerr	..	*Musgrave*	..	..	..	..	..	..	..	..	..	7·4	..
Electrical Co.	..	*Cole, M. & M.*	..	..	..	..	..	..	..	..	..	..	..
	..	*Musgrave*	..	..	..	..	..	..	..	..	..	7·25	..
E.C.C.	..	*Cole, M. & M.*	..	..	..	..	..	..	..	..	..	7·	..

G.E. Co., Ld.	Brush-Parsons	..	Wheeler	..	..	..	..	7·44	..	..	..	..	4·95
	Parsons	..	"	..	..	..	..	7·99	..	..	..	..	5·45
	"	*Musgrave*	..	..	..	..	..	..	..	*0·7*	..	*6·8*	..
	..	*Wallsend Slipway*	..	..	..	..	..	..	..	..	..	*7·55*	..
Howden	..	..	..	..	..	..	..	..	4·5	0·85	0·4	..	..
Lahmeyer	..	*Musgrave*	..	..	..	..	..	..	..	*0·75*	..	*7·65*	..
Mather & Platt	..	..	M. & P.	7·45	..	..	..	..	..	..	..	*7·6*	9·8
"	Zoelly	..	"	..	..	..	..	12·42	..	..	..	..	..
	..	*Combe Barbour*	..	..	..	..	..	..	..	..	..	8·1	..
Parsons	..	..	..	7·15	7·7	6·25	6·4	8·51	5·	0·8	0·3	..	5·6
	..	..	..	..	..	7·	..	..	..	..	..	..	..
Richardson Westgarth	Brown-Boveri Alternator	..	R. W.	6·55	..	7·25	..	8·29	4·85	1·05	..	..	..
Siemens	..	..	..	..	7·9	..	..	..	4·4	0·85	0·35	..	..
	Parsons	..	Worthington	..	..	..	..	9·99	..	..	..	..	..
	Zoelly	..	"	..	..	..	..	10·60	..	..	..	..	..
	Rateau	..	"	..	..	..	..	11·23	..	..	..	..	..
	Willans	..	..	..	7·2	..	..	..	..	..	..	..	..
	..	*Cole Marchent*	..	..	..	..	..	..	..	..	..	*6·85*	..
	..	*Musgrave*	..	..	..	..	..	..	..	*0·75*	..	*7·75*	..
Westinghouse	..	..	Cole, M. & M.	..	..	..	..	8·07	5·1	0·85	0·25	..	5·6
	..	*Musgrave*	..	..	..	..	..	..	..	..	..	*7·3*	..
Willans & Robinson	..	..	..	6·	..	6·85	..	..	4·	0·8	0·35	..	..
	..	..	..	..	..	..	..	..	..	1·0	..	..	..
	Peebles Alternator	..	W. & R.	..	..	..	..	7·45	..	..	..	..	6·05
	D. K. & Co. "	..	"	..	..	..	..	7·58	..	..	..	..	5·5
	Witting "	..	"	..	..	..	..	8·47	..	..	..	..	..
	Siemens "	..	"	..	..	..	..	9·56	..	..	..	..	..
	G. E. Co., Ld. "	..	"	..	..	..	..	..	..	..	..	..	5·55
Witting, Eborall	Zoelly	..	Allen	..	..	..	..	9·52	..	..	..	..	..
	"	..	Cole, M. & M.	..	..	..	..	9·29	..	..	..	..	..
	Richardson	..	Allen	..	..	..	..	8·96	..	..	..	..	..
	"	..	Cole, M. & M.	..	..	..	..	8·73	..	..	..	..	..
	..	Not stated	..	..	..	..	..	..	..	*0·7*	..	*7·7*	..
	..	*D. Stewart*	..	..	..	..	..	..	..	..	..	*8·65*	..
Accepted price reduced to £ per ton									172	62			

TABLE VII.—COMPLETE POWER-HOUSE COSTS PER RATED K.W. INSTALLED, IN DECIMALS OF A POUND.

Item Number.		*Mr W. C. Gotshall's American Reciprocating Engine Plants.* *Maximum.*		*Minimum.*		Yorkshire Power Co.'s Steam Turbine Plant, Thornhill, 6000 K.W.	Reciprocating Plant, 10,000 K.W.	Turbine Plant, 90,000 K.W.	*Reciprocating* Interboro (Subway) New York. 120,000 H.P.
		$	£	$	£	£			
1	Land	..	..	..	..	0·09	..	0·44	
2	Foundations	*3·50*	·7	*1·50*	0·3	..	0·25		
3	Sidings	..	..	..	..	..	..		
4	Roadways	..	..	..	..	..	..	0·56	
5	Landing Stage	..	..	..	..	..	..		
6	Circulating Water Intake and Discharge	..	..	..	..	..	..		
7	Buildings	*15·00*	3·1	*8*	1·6	..	2·0		
8	Chimneys	*2·00*	·4	*1·00*	0·2	..	0·25		
9	Flues					..	..		
10	*Total of items 2 to 9*	..	4·2	..	2·1	2·75	2·5		
11	MACHINERY—								
12	Boilers	*17·00*	3·5	*9·00*	1·8	..	2·5		
13	,, Settings						..		
14	Superheaters	..	..	..	..	..	..		
15	Stokers	*3·00*	0·6	*2·50*	0·5	..	0·5	3·66	
16	,, Drivers	..	..	..	..	..	..		
17	Economisers	*4·50*	0·9	*2·50*	0·5	..	0·3		
18	Coal Conveyor	*6·00*	1·2	2·00	0·4	..	0·4		
19	,, Bunkers						..		
20	Ash Conveyor	*1·50*	0·3	*1·00*	0·2	..	..		
21	Piping	*12·00*	2·5	*4·00*	0·8	..	1·5		
22	,, Covering								
23	Feedwater Heater	*2·00*	0·4	*1·00*	0·2	..	..		
24	Feed Pumps	*1·00*	0·2	*1·00*	0·2	..	0·2		
25	Engines or Turbines	*32·00*	6·6	*20·00*	4·1	..	9		
26	Generators	*21·00*	4·3	*18·00*	3·7	..	3		
27	Exciters	..	..	..	..	..	0·3		
28	Condensers	..	..	..	..	..	0·8	2·17	
29	Air Pumps	..	..	..	..	..	0·5		
30	Circulating Pumps	..	..	..	..	..	0·2		
31	Lift Pumps	..	..	..	..	..	0·1		
32	Switchboard	*4·00*	0·8	*1·50*	0·3	..	0·5		
33	Power-house Cables	*6·00*	1·2	*3·00*	0·6	..	..		
34	,, Conduits								
35	Travelling Crane	..	..	..	..	..	..	0·55	
36	Incidentals (as concrete floor)	*2·00*	0·4	*2·00*	0·4	..	..		
37	*Total of Machinery items*	..	22·9	..	13·7	16	19·8	..	
	Engineering supervision and contingencies 10 per cent.	..	..	..	..	..	..	0·72	
38	Total of items 2 to 36	*132·50*	27·1	*78·00*	15·8	18·75	..	7·96	
38A	Power-house per Horse-power	..	..	..	..	..	..	..	£12 per H.P.
39	A fair average cost per K.W.	105	21·6	..	..	..	..		
40	Transmission System	..	..	..	..	10,000 K.W. 12·7			
41	Substations	45·00	9·2	38·00	7·8				
42	Probable cost complete undertaking	..	..	..	..	£45 per K.W.			
43	Source of Data	*Electric Railway Economics*, by W. C. Gotshall, 1903,[2] M'Graw Pub. Co., New York.				Proc. International Elec. Congress, St Louis, 1904. Mr H. F. Parshall.	Administrative County of London and District Electric Power Co.'s Bill before Parliament, 1905. Mr J. D. Fitzgerald, K.C., stated capacity before Sir James Kitson's Select Committee, July 18, 1905.		"The N.Y. Rapid Transit Subway," by H. C. Fyfe, p. 909, *The Engineering Magazine*, Sept. 1904.

[1] *Elect. Power*, June 1904. Land for ten times this plant, £5500. See Ch. XXII. for details of this plant.
[2] Mr Gotshall said in 1903, "Steam turbine plants cost 70 per cent. of above maximum, and will probably be much less within a few years."

Costs of Complete Power-house.—It will be of interest to put alongside the figures published in America by Mr W. C. Gotshall, the costs of the Yorkshire power plant as published by Mr H. F. Parshall, together with the estimates for the proposed plant of the Administrative County of London and District Electric Power Company, and prices for a 10,000 horse-power reciprocating plant designed by the authors, which gives details of condenser and pump costs, not separately stated in Mr Parshall's figures, and not itemised in Mr Gotshall's costs, but mentioned in his text as an essential part of such a plant.

The following table is an extract inserted here for comparisons:—

TABLE VIII.—COMPARISON OF COST OF DIFFERENT TYPES OF ENGINES.[1]

Cylinders.	Speed.	Exhaust.	Steam Consumption. Lbs. per I.H.P. Hour. Non-Condensing.	Condensing.	Cost per H.P. Engine erected.		[2] Boilers, Buildings, Chimney.		Engine, Boiler, Buildings, Chimney.
					$	£	$	£	£
Simple	High speed	Non-condensing	33	..	17·50	3·6	15·20	3·1	6·7
	,,	Condensing	..	22	21·00	4·3	12·00	2·5	6·8
	Low speed	Non-condensing	29	..	25·00	5·1	14·20	2·9	8·0
	,,	Condensing	..	20	27·00	5·5	11·50	2·4	7·9
Compound	High speed	Non-condensing	26	..	21·00	4·3	13·10	2·7	7·0
	,,	Condensing	..	20	24·50	5·0	11·40	2·3	7·3
	Low speed	,,	..	18	30·00	6·1	11·00	2·3	8·4
Triple ex. compound	High speed	Non-condensing	24	..	26·00	5·3	12·50	2·6	7·9
Triple ex. compound	,,	Condensing.	..	17	29·00	6·0	10·50	2·2	8·2
Triple ex. compound	Low speed	,,	..	16	37·50	7·7	10·30	2·1	9·8
Ditto for probable maximum results			..	14	45·00	9·2	8·15	1·7	10·9

[1] Dr Chas. E. Emery, as quoted by W. C. Gotshall, p. 131, *Street Ry. Economics.*

[2] This column is headed by Gotshall, "Engine, Boiler, Building, and Stack" (chimney), but prices evidently exclude engine.

Cost of Condensing Plant.—Fig. 2 shows the relative cost of condensing equipments, including surface condenser, dry air pump, circulating pump, lift pump from hot well, pipes, and valves, as stated by Mr J. R. Bibbins, p. 186, *Report, American Street Railway Association*, 1904. He took 26 inches as his basis.

Costs of different types of condenser are reproduced in Table IX.

TABLE IX.

Cost of Condensing Plant.	[1] Per Rated K.W. of Plant.
Barometric	25s. to 30s.
Surface Condenser, including— Centrifugal lift pump; An air-cooler; Single-cylinder dry vacuum pump; Centrifugal circulating pump	30s. to 40s.
Surface Condenser, including— Wet vacuum pump; Centrifugal circulating pump	30s. to 40s.
Ejector Condenser	8s. to 10s.

[1] From Mr G. B. Rockwood, before American Soc. Mech. Engrs., 1904.

It is also of interest to reproduce, by permission, Mr W. H. Allen's costs of 1000 kilowatt condensing and non-condensing

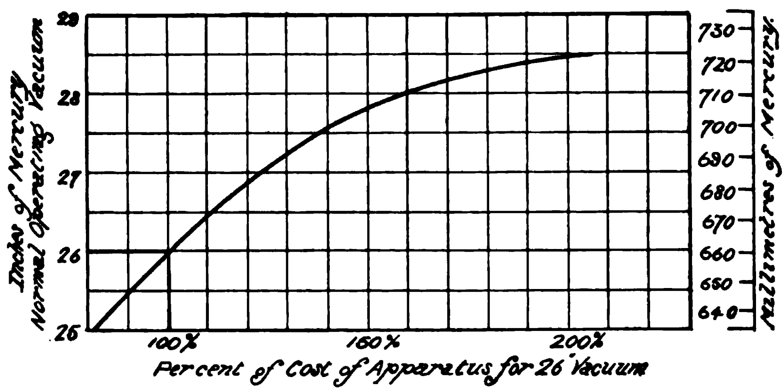


FIG. 1.—Relative Cost of Condensing Equipments.

plants, together with his curves of saving in running costs due to use of condensers. These fix a definite value on the advantages of using condensers.

It is of interest to follow Mr W. H. Allen further, as he gave definite "fair commercial" values to the saving (as a percentage of working expenses) due to condensing in different sizes of plants up to the above 1000 K.W. His curve is reproduced in Fig. 2, by permission, from the *Proceedings of the Institution of Civil Engineers* Feb. 28, 1905, p. 222,—Discussion on Mr R. W. Allen's paper on "Surface Condensing Plants."

TABLE X.—MR W. H. ALLEN'S COMPARATIVE CAPITAL COSTS AND WORKING COSTS OF 1000 K.W. CONDENSING AND NON-CONDENSING PLANTS.

Proceedings, Institution of Civil Engineers, Feb. 28, 1905, p. 221.

Capital Cost.	Cost in £ per Rated K.W.			
	Non-condensing.		Condensing.	
Engine and dynamo	*Steam 27·5 lbs. per K.W.H.*	5·475	*21 lbs. per K.W.H.*	5·275
Boilers	*Four 27,500 lbs. per hour*	2·199	*Three 22,000 lbs. per hour*	1·650
Feed heater	*27,500* „	0·250	*Make-up feed 2,200* „	0·050
Feed pumps	*27,500* „	0·090	*22,000* „	0·075
Pipework		0·150		0·250
Foundations		0·250		0·200
Chimney		0·600		0·500
Surface condensing plant			*22,000 lbs. per hour,* *25 inches vacuum,* *80° F. circulating supply,* *93% dynamo efficiency*	0·955
Cooling tower and foundations				0·700
Oil separator				0·180
		9·014		9·835
Working Cost	**Working Cost £ per annum. 280 days of 10 hours.**			
	Non-condensing.		**Condensing.**	
Water at 9d. per 1000 gallons	2800 + 10 per cent. loss gallons per hour	£322	1600 gallons per hour make up for cooling tower 220 gallons per hour make-up feed	£168 23
Coal at 20s. per ton	1·52 tons per hour 2·45 lbs. per K.W.H. 1·7 „ B.H.P.H.	4250	1·09 tons per hour 3·4 lbs. per K.W.H. 2·36 lbs. per B.H.P.H.	3050
Labour	4 men	200	3 men	150
12½ per cent. interest and Depreciation	on £9014	1128	on £9835	1230
		£5900		£4621
Balance in favour of Condensing, 21·6 per cent. on £5900				1279
				£5900

Buildings and superheat are the same in each case.

Weight.—In the paper which has been already referred to in this chapter, Chilton has given the interesting data set forth in Table XI.

Cost per ton.—The cost per ton, as derived from the data in the preceding paragraphs, is stated when weight is known.

Speed.—For land plants it has come to be assumed that there is no alternative but to run steam turbines at speeds several

times greater than those of the highest-speed reciprocating engines. One need not investigate deeply to discover that this is a hasty conclusion. Thus marine steam turbines are being built for speeds and weights differing far less than those from the speeds and weights of piston engines. The tests of vessels equipped with both types of engine have demonstrated that while

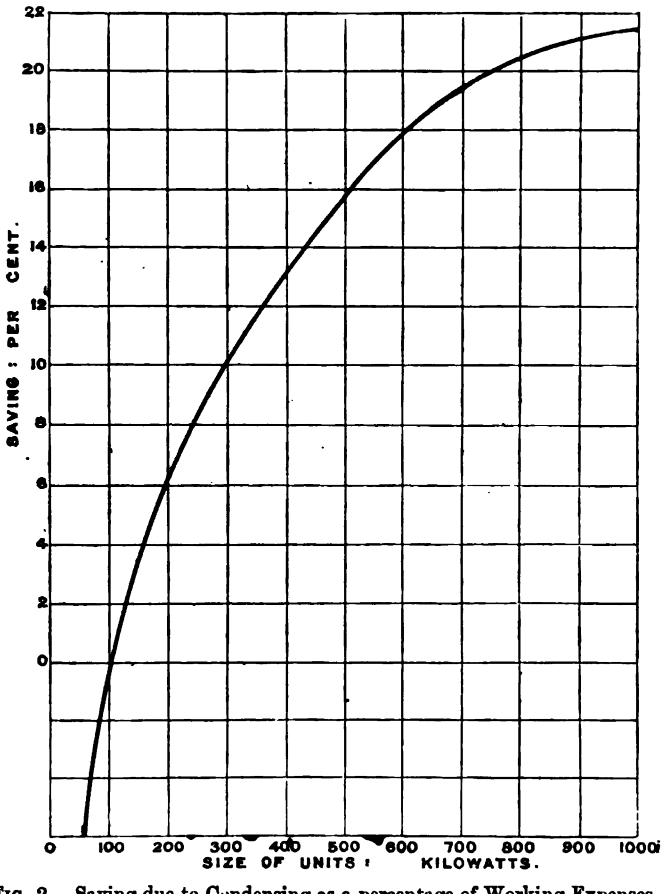


FIG. 2.—Saving due to Condensing as a percentage of Working Expenses.

at high speeds the turbine vessels excel in economy, the steam consumption down to fairly low speeds is but little in excess of that of the piston engine. For the Cunard liners now approaching completion the four turbines constituting the equipment of one vessel are of 75,000 horse-power, and run at a normal speed of 160 revolutions per minute.

TABLE XI.—COMPARATIVE WEIGHTS OF PISTON ENGINES AND TURBINES (EXCLUSIVE OF DYNAMOS), IN METRIC TONS, *i.e.* IN TONS OF 1000 KGS. (2204 LBS.)

Kilowatts Output.	Weight of Slow-speed Engine.	Ditto Weight of Flywheel.	Weight of High-speed Engine.	Weight of Turbine.
500	140	27	30	9
750	190	43	45	12
1000	250	59	60	14
1500	380	88	90	21
1800	450	100	110	23
2000	530	120	120	25
2500	700	145	155	27
3000	...	...	...	32
3500	...	...	...	35
5000	...	...	...	42

The fact that turbine vessels generally weigh practically as much as vessels equipped with piston engines indicates that, when run at speeds comparable to the speeds of piston engines, the turbine loses its advantage of less weight. Nevertheless, it is fairly apparent that the turbine can be designed for good economy at far lower speeds than are commonly associated with it. This is most important, since the dynamo would not only be better, but actually cheaper, at lower speeds than those now customary for land turbines. For continuous current sets, a radical reduction of speed is essential before satisfactory sets of large capacity will become practicable. For alternating current sets much more moderate reductions in speed will lead to satisfactory designs at minimum cost, and one should differentiate between high periodicity and low periodicity sets, the preferable speed for the former being higher than for the latter.

Some data has been published by Grauert, showing the effect of the speed on the economy.

Emmett has also published tests showing the effect of speed on economy.

The Humboldt Co. have built 100 horse-power and 150 horse-

power turbines with two different wheel diameters, and the economy results for the 100 horse-power machine, at an absolute admission pressure of 13 kilograms per square centimetre saturated steam and a 92 per cent. vacuum, are given in Table XII.

TABLE XII.

Rated output in horse-power . .	100	
Diameter of rotor in mm. . . .	500	400
Speed of wheel in revolutions per minute	12,600	12,600
Peripheral speed in metres per second.	330	264
Full load steam consumption in Kgs. per kilowatt-hour	12	13·6

From these results it appears that in this particular case an increase of $100 \times \frac{330-264}{264} = 25$ per cent. in the peripheral speed effects a decrease of $100 \times \frac{13{\cdot}6-12}{13{\cdot}6} = 12$ per cent. in the steam consumption.

Also, for this 100 horse-power machine, from an inspection of Table (p. 40), the percentage gain in steam consumption due to an increase in peripheral speed appears to be approximately the same for all values of admission pressure of the steam.

Peripheral Speeds of Wheels.—Practice varies greatly as to the peripheral speeds of the rotors of steam turbines. A number of instances have been brought together in Table XIII., where are also set forth, in some cases, the wheel diameters, the speeds in revolutions per minute, and the centrifugal force at the periphery, in kilograms per kilogram.

Peripheral Speeds × Pressure at Bearings.—For Parsons' turbines the product of feet per second and lbs. per square inch at bearings has been stated to be 2500 to 3000. In the Brush Parsons 1000 K.W. unit this product is 1500.

The peripheral speeds at bearings are stated for a few units in Table XIII.

Table XIII. brings together the peripheral speeds, centrifugal force at periphery of largest circumference, and the rated output per moving vane for some sizes of each type of turbo-generator.

TABLE XIII.

Type.	Rated Output in K.W.	Speed in R.p.m.	Largest Diameter of Rotor to Middle of Vanes (Metres).	Peripheral Speed in Metres per Sec.	Centrifugal Force at Periphery in Kgs. per Kg.	Peripheral Speed at Bearings.	Number of Moving Vanes.	Rated K.W. Output per Moving Vane.
De Laval	1	40,000	0·075	158	64,000	..	..	..
	1·6	30,000	0·10	,,	28,000	..	..	..
	3	,,	,,	,,	,,	..	44	0·07
	6	24,000	0·12	133	30,000	..	..	..
	10	,,	0·15	167	48,000	19	110	0·09
	19·6	20,000	0·2	210	45,000	..	..	..
	33	16,400	0·3	256	44,000	22	..	..
	50	,,	,,	,,	,,	..	..	..
	74·6	13,000	0·5	340	47,000	..	202	0·37
	112	12,600	,,	,,	,,	..	..	..
	209	10,500	0·76	420	,,	23	196	1·06
Parsons	500	3,000	0·6	90	2,700	..	..	..
	750	1,500	0·9	70	1,100	..	15,000	0·06
	1,000	1,800	0·8	75	1,400	..	20,000	0·10
	2,500	1,800	1·3	92	1,300	..	..	..
Parsons Marine	..	..	..	*30 to 70*	s.s. *Victorian*		750,000	..
					s.s. *Carmania*		1,500,000	..
Westinghouse-Parsons	500	..	..	..	..	..	16,000	0·03
	750	..	..	..	..	..	15,000	0·05
	1,500	1,200	1·9	120	1,500	..	,,	0·10
	2,000	..	..	..	..	..	20,000	,,
	3,500	1,000	1·72	91	960	20	..	..
	5,500	,,	2	103	1,100	..	..	..
Curtis (vertical)	..	..	..	100 to 125	..	..	..	..
	500	..	..	..	..	..	840	0·6
	5,000	514	4·1	110	600	..	..	..
Rateau	100	3,000	0·9	140	4,500	..	..	..
	225	1,600	0·88	75	1,700	..	..	..
	450	1,500	1·02	80	1,300	..	..	..
Zoelly	370	3,000	1·15	180	5,800	..	1,230	0·3
Riedler-Stumpf	15	3,500	0·8	148	5,500	..	..	..
	500	750	3	118	940	..	..	..
	2,000	,,	,,	,,	,,	..	..	..
	1,475	3,000	2	314	10,000	..	150 pairs	4·9 pr. ½ vane
A.E.G.	10	4,000	0·5	105	4,500	..	..	..
	20	3,600	0·64	120	4,600	..	..	..
	470	3,000	1·7	267	8,500	..	..	..
Hamilton-Holzwarth	1,000	1,500	3·1	240	3,900	..	4,800	0·21
Elektra	7	4,000	0·38	80	3,400	..	..	..

Revolutions per Minute. — In Table XIV. are brought together, for turbo-generators of various types, the speeds and the rated output in kilowatts for all sizes.

TABLE XIV.

K.W.	De Laval.	Parsons. Own.	Parsons. Westinghouse.	Parsons. Brush.	Curtis. C.C.	Curtis. A.C.	Rateau. C.C.	Rateau. A.C.	Zoelly.	Riedler-Stumpf.	A.E.G. C.C.	A.E.G. A.C.	Hamilton-Holzwarth.	Elektra.	Union.
1	40,000	..	..	..	*5,000*	..	..	..	..	..	..	..	..	..	..
2	30,000	..	..	..	..	..	..	..	..	..	*5,000*	..	..	..	..
3	,,	..	..	..	..	..	..	..	..	..	..	..	..	..	..
5	..	..	..	..	..	..	..	..	..	..	*4,500*	..	..	..	..
6	24,000	..	..	..	..	..	..	..	..	..	..	..	..	..	..
7	..	..	..	..	..	..	..	..	..	..	..	..	..	4,000	..
10	,,	..	..	..	..	..	..	..	..	..	..	4,000	..	..	..
15	..	..	..	..	4,000	..	..	..	..	3,500	..	..	..	..	..
20	20,000	..	..	..	..	..	..	..	..	..	..	..	..	..	..
25	..	..	..	..	3,600	..	..	..	..	..	..	3,600	..	..	..
33	16,400	..	..	..	..	..	..	..	..	..	..	..	..	..	..
37	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3,500
50	,,	..	..	..	..	..	..	..	..	..	*3,000*	..	..	..	..
75	13,000	..	..	..	*2,400*	..	..	..	..	..	..	..	..	..	..
100	..	..	..	..	..	3,600	..	3,000	..	..	..	3,000	..	3,000	..
112 to 120	12,600	..	..	..	..	..	*2,000*	,,	..	..	..	..	..	..	..
150 ,, 160	..	..	..	..	*2,000*	..	..	3,200	..	..	..	..	..	..	..
209	7,500	..	..	..	..	..	..	..	..	..	..	..	..	..	..
,,	10,500	..	..	..	..	..	..	..	..	..	..	..	..	..	..
225	..	..	..	..	..	..	..	1,600	..	..	..	..	..	...	..
230	..	..	..	..	..	..	..	2,500	..	..	..	..	..	..	..
280	..	..	..	..	..	..	..	3,000	..	..	..	..	..	..	..
300	..	..	3,600	..	*1,800*	..	..	..	..	..	*3,000*	..	..	..	..
325 to 350	..	..	..	..	*2,000*	.	*1,600*	3,000	..	..	..	..	..	..	..
370	..	..	..	..	..	..	..	2,400	3,000	..	..	..	..	..	..
420	..	..	..	..	..	..	..	2,500	..	..	..	..	..	..	..
450	..	..	..	..	..	..	..	1,500	..	..	..	..	..	..	..
470	..	..	..	..	..	..	..	..	..	..	..	3,000	..	..	..
500	..	3,000	..	..	..	1,800	..	..	..	750	*2,000*	..	..	..	..
600 to 650	..	..	..	..	*1,800*	..	*1,300*	2,000	..	..	..	..	..	..	..
750 ,, 800	..	1,500	..	..	..	1,500	..	1,500	..	..	*1,500*	..	..	..	..
1,000	..	1,800	..	..	..	1,200	..	..	..	..	..	3,000	1,500	..	..
,,	..	..	..	..	..	1,500	..	..	..	..	..	..	..	..	..
1,250	..	..	1,200	..	..	..	..	..	..	..	..	..	..	..	..
1,500	..	1,000	,,	..	..	800	..	..	..	..	..	1,500	..	..	..
,,	.	..	..	..	..	1,000	..	..	..	..	..	..	..	..	..
1,800	..	1,200	..	..	..	..	..	..	..	..	..	..	..	..	..
2,000 to 2,600	..	1,260	..	..	*750*	750	..	..	1,200	750	..	..	..	..	..
3,000 ,, 3,500	..	1,360	1,000	..	..	600	..	1,000	..	..	..	1,500	..	..	..
4,000	..	..	..	..	..	..	..	,,	..	..	..	1,000	..	..	..
5,000	..	..	750	..	..	514	..	..	..	..	..	..	..	..	..
5,500	..	..	1,000	..	..	..	..	..	..	..	..	..	..	..	..
6,000	..	..	..	..	..	..	..	..	..	..	..	1,000	..	..	..
7,500	..	..	750	..	..	..	..	..	..	..	..	..	..	..	..
8,000	..	..	..	..	..	750	..	..	..	..	..	..	..	..	..

CHAPTER II

NOMENCLATURE

THE diversity in units employed in steam engineering has, to a greater degree even than in other departments of engineering, constituted a grave hindrance to progress.

Expressions for Energy.—The British Thermal Unit is generally employed in English-speaking countries in expressing the calorific power of fuels and in steam tables. This is generally denoted by B.Th.U.[1] One B.Th.U. is the amount of energy which must be added to one pound of water at a temperature of 32° Fahr., to raise its temperature by 1° Fahr.

A far more satisfactory unit, the kilogram-calorie (or "large calorie" in contradistinction to the "gram-calorie" or "small calorie"), is employed for these purposes in most other countries. This quantity is denoted by the letters W.E. ("Wärme Einheit" or "heat unit") in German technical literature. We shall employ the letters Kg.C. for this quantity. The kilogram-calorie is the amount of energy which must be added to one kilogram (one litre) of water at 4° Cent. to raise its temperature by 1° Cent.

The Kg.C. is a far more scientific unit than B.Th.U., and it is to be hoped that it will ultimately find its way into English technical literature, and, endowed with some satisfactory name, become the universal practical unit of energy.

With a view to the ultimate attainment of this end, and also in recognition of the fact that there is no reason for employing different units for heat energy and mechanical energy, the authors propose in this treatise to frequently employ the alternative unit, the kilowatt-hour, denoted by the letters K.W.H. This is sometimes designated in England as the Board of Trade Unit. The use

[1] Commonly known as B.T.U. in the United States; but B.T.U. is commonly used in Great Britain to mean K.W.H. or "Board of Trade Unit."

of the expression K.W.H. has the advantage of having been universally adopted throughout the technical world as an expression for electrical energy, and it is equally suitable as an expression for mechanical energy and for heat energy.

We believe that the advantages of expressing these three forms of energy in the same terms will appeal to engineers; and while we should have preferred the kilogram-calorie (Kg.C.) for this universal unit of energy, we are convinced that but little headway could be made in a lifetime in replacing the British Thermal Unit (B.Th.U.) and the horse-power hour by the kilogram-calorie (Kg.C.). On the other hand, the engineering profession throughout the world has shown considerable and often spontaneous readiness to employ the kilowatt-hour (K.W.H), not only as an expression for electrical energy, but, to a large extent, also for mechanical energy, and we do not anticipate insuperable difficulty in promptly obtaining for the kilowatt-hour (K.W.H.) a fairly extended use as an expression for heat energy. It will become the task of a later generation to substitute the kilogram-calorie (Kg.C.), as general unit of energy, for the then universally adopted kilowatt-hour (K.W.H.).

The horse-power hour need rarely be mentioned. So far as reference need be made to it in this treatise, we shall denote it by the letters H.P.H.

The same remarks apply to the foot-pound and the metre-kilogram, which are expressed by the letters ft.-lb. and m.-kg. respectively.

TABLE XV.—ENERGY, WORK AND HEAT UNITS, WITH ABBREVIATIONS AND CORRESPONDING VALUES EXPRESSED IN JOULES.[1]

Unit.	Abbreviation.	Value in Joules.
1 kilowatt-hour	1 K.W.H.	3,600,000
1 kilogram-calorie . . .	1 Kg.C.	4,190
1 kilogram-metre . . .	1 Kg. m.	9·81
1 horse-power hour . . .	1 H.P.H.	2,680,000
1 British thermal unit. . .	1 B.Th.U.	1,055
1 foot pound	1 ft. lb.	1·356

[1] The Joule may be defined as 10^7 ergs, or as one watt second.

Practical Units for Power.—For unit of power we shall employ the kilowatt (K.W.) to as great an extent as practicable, and often also the horse-power (H.P.), owing to the wide use which it still unfortunately enjoys. The Kg.C.S., by which we denote one kilogram-calorie (one Kg.C.) per second, will, we hope, ultimately come to be adopted as the commercial unit for power. It should, however, be given some appropriate name.

So far as is reasonable, we shall endeavour to often employ more than one alternative unit in the text, tables, and curves, and we trust that this will render our work more useful to those accustomed to particular units. We hope it will not encourage procrastination on the part of any engineers in familiarising themselves with the metric system.

The following tables will be useful in transforming values from one set of units to another.

TABLE XVI.—POWER UNITS, WITH ABBREVIATIONS AND THEIR CORRESPONDING VALUES EXPRESSED IN WATTS.

Unit.	Abbreviation.	Value in Watts.
1 kilowatt	1 K.W.	1000
1 kilogram-calorie per second .	1 Kg.C.S.	4190
1 kilogram-metre per second .	1 Kg.M.S.	9·81
1 horse power	1 H.P.	746
1 British thermal unit per second	1 B.Th.U.S.	1055
1 foot-pound per second . .	1 ft. lb. s.	1·356

TABLE XVII.—EQUIVALENT VALUES FOR WORK, ENERGY AND HEAT, EXPRESSED IN DIFFERENT UNITS (ENGLISH AND METRIC).

	K.W.H.	Kg.C.	Kg.M.	H.P.H.	B.Th.U.	Ft. lb.
1 K.W.H. is equal to .	1	860[1]	367000	1·34	3411	2654000
1 Kg.C. is equal to .	0·00116	1	427	0·001559	3·97	3081
1 Kg.M. is equal to .	0·00000272	0·00234	1	0·00000365	0·00930	7·23
1 H.P.H. is equal to .	0·746	641	274000	1	2545	1980000
1 B.Th.U. is equal to .	0·000293	0·252	107·6	0·000393	1	778
1 ft. lb. is equal to .	0·000000377	0·000324	0·1382	0·000000505	0·001285	1

It may be of interest to students to follow the deduction of the value of 1 K.W.H. in Kg.C. by converting through the British units, as this will set forth the interconnection of the various units employed.

746 watts = 33,000 ft. lbs. per minute = 1 British H.P.

$$\therefore \quad 1 \text{ K.W.} = \frac{1000}{746} \times 33{,}000 = 44{,}235 \text{ ft. lbs. per minute.}$$

$$= 737{\cdot}2 \text{ ft. lbs. per second.}$$

$$\therefore \quad 1 \text{ K.W. second} = 737{\cdot}2 \text{ ft. lbs.}$$

$$1 \text{ K.W. hour} = 3600 \times 737{\cdot}2 = 2{,}654{,}000 \text{ ft. lbs.}$$

The mechanical equivalent of 1 B.Th.U. = 778 ft. lbs., or 778 ft. lbs., raise 1 lb. of water 1° Fahr. at 60° F. This is Joule's equivalent.

$$\therefore \quad \frac{9}{5} \times 2{\cdot}2 \times 778 = 3080 \text{ ft. lbs. raise 1 Kg. of water 1° Cent.}$$

$$\therefore \quad 3080 \text{ ft. lbs.} = 1 \text{ large calorie.}$$

$$\therefore \quad 1 \text{ K.W. hour} = \frac{2654000}{3080} = 860 \text{ Kg.C.}$$

TABLE XVIII.—EQUIVALENT VALUES FOR POWER EXPRESSED IN DIFFERENT UNITS (ENGLISH AND METRIC).

	K.W.	Kg.C.S.	Kg.M.S.	H.P.	B.Th.U.S.	Ft. lbs. S.
1 K.W. is equal to .	1	0·238	102·0	1·34	0·947	737
1 Kg.C.S. is equal to .	4·20	1	427	5·61	3·97	3088
1 Kg.M.S. is equal to .	0·00981	0·00234	1	0·01315	0·00930	7·23
1 H.P. is equal to . .	0 746	0·1781	76·0	1	0·707	550
1 B.Th.U.S. is equal to	1·055	0·252	107·6	1·415	1	778
1 ft. lb. s. is equal to. .	0·001356	0·000324	0·1383	0·001818	0·001285	1

TABLE XIX.—LENGTHS.

	Feet.	Yards.	Statute Miles.	Nautical Miles.	Metres.	Kilo-metres.	German Sea Miles.
1 foot equals	1	0·3333	·0001894	0·0001644	0·3048	3048/10^7	0·0001646
1 yard	3	1	·0005682	0·000493	0·9144	9144/10^7	0·000494
1 statute mile .	5280	1760	1	0·8684	1609·3	1·6093	0·8690
1 nautical mile . . .	6080	2026	1·1515	1	1853·2	1·8532	1·0007
1 metre	3·2809	1·0936	·0006214	·0005396	1	0·001	0·00054
1 kilometre	3280·9	1093·6	0·6214	0·5396	1000	1	0·5400
1 German sea mile . .	6075·9	2025·3	1·1507	0·9993	1851·9	1·8519	1

TABLE XX.—AREAS AND VOLUMES.

	Areas.				
	Square Inches.	Square Feet.	Square Yards.	Square Centimetres.	Square Metre.
1 square inch . . .	1	·006944	·0007716	6·451	·0006451
1 „ foot . . .	144	1	0·1111	929	0·0929
1 „ yard . . .	1296	9	1	8361	0·8361
1 „ centimetre . .	0·1550	·001076	·0001196	1	0·0001
1 „ metre . . .	1550	10·76	1·196	10000	1
	Volumes.				
	Cubic Inches.	Cubic Feet.	Cubic Yards.	Cubic Centimetres.	Cubic Metres.
1 cubic inch . . .	1	·0005787	·00002143	16·386	1639/10⁸
1 „ foot . . .	1728	1	0·0370	28310	0·0283
1 „ yard . . .	46660	27	1	764500	0·7645
1 „ centimetre . .	0·0610	0·000035	0·0000013	1	10^{-6}
1 „ metre . .	61030	35·32	1·3080	10^6	1

TABLE XXI.—WEIGHTS AND PRESSURES.

	Weights.			
	Lbs.	Long Ton.	Kgs.	Metric Tons.
1 lb. (pound av.). . . .	1	·000446	0·4536	·0004536
1 ton (long ton)	2240	1	1016	1·016
1 kilogram	2·205	·000984	1	0·001
1 metric ton	2205	0·9842	1000	1
	Pressures.			
	Lbs. per Sq. Inch.	Kgs. per Sq. Cm.	Inches of Mercury.	Mms. of Mercury.
1 lb. per sq. inch. . . .	1	0·0703	2·036	51·71
1 kg. per sq. cm.. . . .	14·22	1	28·96	735·5
1 inch of mercury . .	0·4912	0·0345	1	25·4
1 millimetre of mercury .	0·0193	0·00136	0·03937	1

TABLE XXII.—POWER.

	B.H.P.	Ft. Lbs. per Second.	Metr. H.P.	Kgms. per Second.
1 B.H.P.	1	550	1·014	76·04
1 ft. lb. per second . .	0·00182	1	0·01843	0·1383
1 metr. H.P. . . .	0·9863	542·47	1	75
1 kgm. per second . .	0·01315	7·233	0·0133	1

We wish to express regret that England and America adhere so persistently to antiquated and inferior systems of units. Throughout the Continent of Europe, steam engineers are employing the metric system; and largely in consequence of this circumstance there is a close understanding between steam and electrical engineers. On the Continent of Europe the younger generation of engineers is being educated to employ the metric system exclusively. To these circumstances, in our opinion, is to be attributed, far more than to some other alleged causes, the rapid rate at which Germany and Switzerland are coming to the front as rivals of English-speaking countries in manufacture and commerce.

TABLE XXIII.—EQUIVALENT VALUES FOR SPEED EXPRESSED IN DIFFERENT UNITS (ENGLISH AND METRIC).

	Miles per Hour.	Knots.	Feet per Second.	Kilometres per Hour.	Metres per Second.
1 mile per hour . . .	1	0·8684	1·467	1·609	0·4470
1 knot (nautical m. per hour)	1·152	1	1·689	1·853	0·515
1 foot per second . .	0·682	0·592	1	1·097	0·305
1 kilometre per hour . .	0·621	0·54	0·911	1	0·278
1 metre per second . .	2·237	1·943	3·28	3·6	1

Equivalent Values for Speeds.—To facilitate the conversion of speeds from one system of units to another, we have given in Table XXIV. equivalent values of speeds, expressed in metres per second, feet per minute, etc., for speeds ranging from 1 metre per second to 100 metres per second. Speeds greater than 100 m. sec. can be easily converted by simple multiplication; thus for 220 metres per second the same sequence of figures holds as for 22 metres per second.

TABLE XXIV.

Metres per Second.	Kilometres per Hour.	Miles per Hour.	Feet per Minute.	Feet per Second.	Metres per Second.	Kilometres per Hour.	Miles per Hour.	Feet per Minute.	Feet per Second.
1	3·6	2·24	197	3·28	51	183·6	114·2	10,050	167·3
2	7·2	4·48	394	6·56	52	187·2	116·5	10,240	170·6
3	10·8	6·72	591	9·84	53	190·8	118·7	10,440	173·8
4	14·4	8·96	788	13·1	54	194·4	121·0	10,640	177·1
5	18·0	11·2	985	16·4	55	198·0	123·2	10,840	180·5
6	21·6	13·4	1180	19·7	56	201·6	125·4	11,030	183·7
7	25·2	15·7	1380	24·0	57	205·2	127·7	11,230	187·0
8	28·8	17·9	1580	26·2	58	208·8	129·9	11,430	190.2
9	32·4	20·2	1780	29·5	59	212·4	132·2	11,620	193·5
10	36·0	22·4	1970	32·8	60	216·0	134·4	11,820	196·8
11	39·6	24·6	2170	36·1	61	219·6	136·6	12,020	200·1
12	43·2	26·9	2360	39·4	62	223·2	138·9	12,210	203·4
13	46·8	29·1	2561	42·6	63	226·8	141·1	12,410	206·6
14	50·4	31·4	2760	45·9	64	230·4	143·4	12,610	209·9
15	54·0	33·6	2960	49·2	65	234·0	145·6	12,810	213·2
16	57·6	35·8	3152	52·5	66	237·6	147·8	13,000	216·5
17	61·2	38·1	3350	55·8	67	241·2	150·1	13,200	219·8
18	64·8	30·3	3550	59·0	68	244·8	152·3	13,400	223.0
19	68·4	42·6	3740	62·3	69	248·4	154·6	13,590	226·3
20	72·0	44·8	3940	65·6	70	252·0	156·8	13,790	229·6
21	75·6	47·0	4140	68·9	71	255·6	159·0	13,990	232·9
22	79·2	49·3	4334	72·2	72	259·2	161·3	14,180	236·2
23	82·8	51·5	4530	75·4	73	262·8	163·5	14,380	239·4
24	86·4	53·8	4730	78·7	74	266·4	165·8	14,580	242·7
25	90·0	56·0	4930	82·0	75	270·0	168·0	14,780	246·0
26	93·6	58·2	5120	85·3	76	273·6	170·2	14,970	249·3
27	97·2	60·5	5320	88·6	77	277·2	172·5	15,170	252·6
28	100·8	62·7	5520	91·8	78	280·8	174·7	15,370	255·8
29	104·4	65:0	5710	95·1	79	284·4	177·0	15,560	259·1
30	108·0	67·2	5910	98·4	80	288·0	179·2	15,760	262·4
31	111·6	69·5	6110	101·9	81	291·6	181·4	15,960	265·7
32	115·2	71·7	6300	105·0	82	295·2	183·7	16,150	269·0
33	118·8	73·9	6500	108·2	83	298·8	185·9	16,350	272·2
34	122·4	76·2	6700	111·5	84	302·4	188·2	16,550	275·5
35	126·0	78·4	6900	114·8	85	306·0	190·4	16,750	278·8
36	129·6	80·6	7090	118·1	86	309·6	192·6	16,940	282·1
37	133·2	82·9	7290	121·4	87	313·2	194·9	17,140	285·4
38	136·8	85·1	7490	124·6	88	316·8	197·1	17,340	288·6
39	140·4	87·4	7680	127·9	89	320·4	199·4	17,530	291·9
40	144·0	89·6	7880	131·2	90	324·0	201·6	17,730	295·2
41	147·6	91·8	8080	134·5	91	327·6	203·8	17,930	298·5
42	151·2	94·1	8270	137·8	92	331·2	206·1	18,120	301·8
43	154·8	96·3	8470	141·0	93	334·8	208·3	18,320	305·0
44	158·4	98·6	8670	144·3	94	338·4	210·6	18,520	308·3
45	162·0	100·8	8870	147·6	95	342·0	212·8	18,720	311·6
46	165·6	103·0	9060	150·9	96	345·6	215·1	18,910	314·9
47	169·2	105·3	9260	154·2	97	349·2	217·3	19,110	318·2
48	172·8	107·5	9460	157·4	98	352·8	219·5	19,310	321·4
49	176·4	109·8	9650	160·7	99	356·4	221·8	19,500	324·7
50	180·0	112·0	9850	164·0	100	360·0	224·0	19,700	328·0

So far as costs and prices are mentioned, these are often expressed decimally in pounds or shillings or pence: thus £10·5 denotes ten and one half pounds, and not ten pounds five shillings. The decimal system is appreciated by everyone who has taken the pains to become acquainted with its simplicity.

CHAPTER III

THE DE LAVAL TURBINE

THE de Laval turbine is an excellent instance of rational engineering development. In 1883 we find de Laval working, but in the

FIG. 3.—Hero's Turbine, B.C. 120.

light of modern knowledge, on the lines of Hero's turbine of B.C. 120, or thereabouts. In Figs. 3 and 4 these two turbines are illustrated side by side.

For some years de Laval appears to have continued his investigations along the lines of the Hero type (see British Patent No. 16020 of 1886), but in 1889 there was granted to de Laval British Patent No. 7143, in which we find the inventor occupied with the

type of turbine invented by Branca in 1628, and illustrated in Fig. 5, side by side with an illustration of the wheel and nozzles of a modern de Laval turbine.

While the present treatise does not primarily concern itself with the historical development of the modern steam turbine, nevertheless, inasmuch as the Hero and Branca types are representative of the two fundamental ideas on one or the other or both of which the action of all steam turbines is based, it is of use

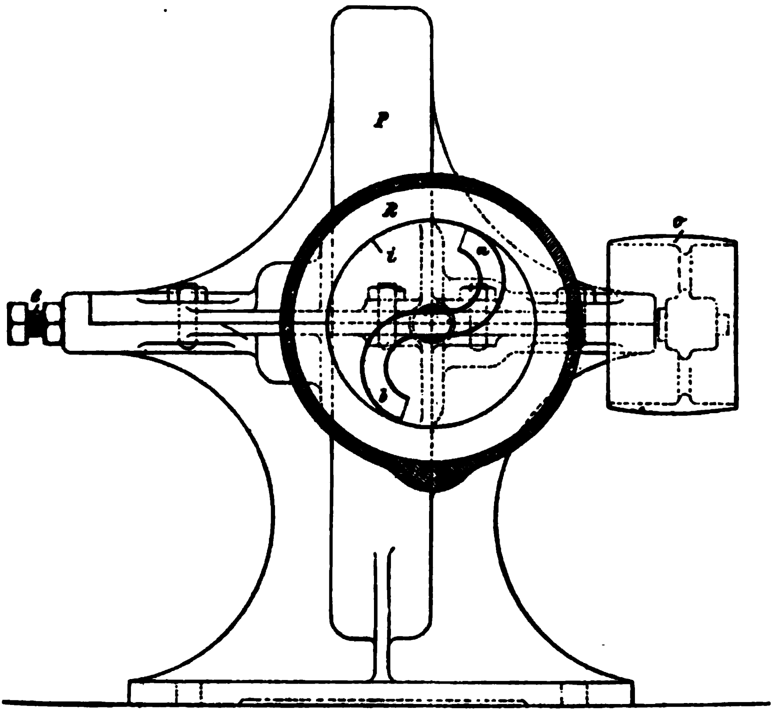


FIG. 4.—De Laval Turbine, A.D. 1883.
(*From Patent* 1655.)

to reproduce these two familiar illustrations of the Hero and Branca types respectively. Nor would we belittle de Laval's work in investigating these older types. For this great engineer, after thoroughly investigating their possibilities, and having finally decided in favour of the Branca type, proceeded to carry out a programme of strikingly original inventive work which resulted in the production of a steam turbine, various of the features of which have become fundamental principles underlying much of the most important modern steam turbine development. Never-

theless, the type of turbine developed under de Laval's personal direction, and universally known under his name, appears, pending radical developments, to have reached its limitations so far as relates to the capacity of a single machine. While several manufacturers of other types are supplying steam turbines of from 5000 to 10,000 horse-power capacity per machine, the largest size supplied by the de Laval companies remains at 300 horse-power. From this capacity downwards, however, the de Laval turbine is in far more extensive use than any other type, having now for all countries a record of some 5000 steam turbines installed, comprising motors, electric generating sets, pumps and ventilators. The aggregate rated capacity of these 5000 turbines is over

FIG. 5A.—Branca, 1628.

FIG. 5B.—De Laval.

150,000 horse-power, or an average rated capacity of some 30 horse-power per turbine.

THE DIVERGING NOZZLE INTRODUCED BY DE LAVAL.

The most important feature introduced by de Laval is that of the diverging nozzle (see British Patent No. 7143 of 1889), the principle of which has greatly influenced the development, not only of the de Laval type, but of steam turbines in general. Fig. 6 is taken from de Laval's British Patent No. 7143 of 1889, the text of which, owing to its importance and brevity, we reproduce as follows :—

"My invention relates to an improvement in turbines which are set in motion by means of a current of steam ; and the object of the improvement is to increase, by complete expansion, the velocity of the steam current, thus producing the relatively largest quantity of *vis viva* of the steam.

"I attain this object by the construction of the steam supply

pipe in such a manner that the cross sections of the same are slowly increased near to the turbine wheel and in the direction of the latter. The ratio of increasing the cross sections is due to the proportion and distance between the smallest section and the largest one, in such a manner that in the steam passage between these two sections a permanent current of steam is produced under isoëntropical expansion.

"The accompanying drawing, in which is a front view and a side elevation, both partly in section, shows the mouthpiece of a steam supply M, constructed as above described, in

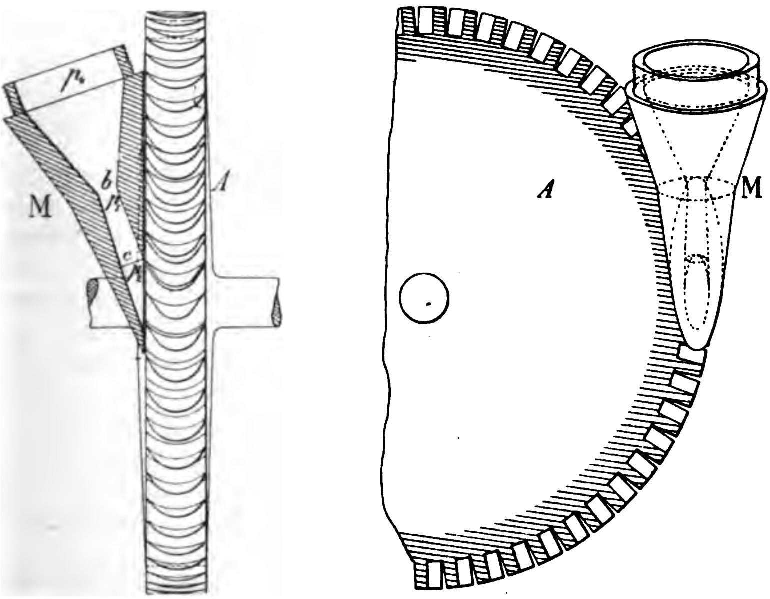


Fig. 6.—De Laval's Expanding Nozzle, 1889.

combination with a turbine wheel A. *b* is the smallest and *c* the largest cross section. Between both these sections the steam expands from the pressure 0·557 P_0 (P_0 = boiler pressure) to the pressure of the receiver (= P_2).

" Having now particularly described and ascertained the nature of my said invention, and in what manner it is to be performed, I declare that what I claim is:—

" In steam turbines, the combination of the turbine wheel with a steam supply, the cross sections of which increase regularly near to the turbine wheel and in the direction of the same, substantially as and for the purpose specified."

RELATIVE SPEED OF STEAM AND TURBINE.

From the above patent description alone, the significance of the diverging nozzle is not immediately apparent. The following rough elementary considerations may be useful.

In the first place, it will be well to explain the action of the de Laval type of steam turbine by a hypothetical example:—

Suppose a perfectly elastic body[1] with a mass, M, weighing one kg., to be travelling in a straight line through a frictionless medium (in a region where $g=9{\cdot}8$ metres per second), at a uniform velocity, V, of 1000 metres per second. The kinetic energy of this body, *i.e.* the energy possessed by it in virtue of its motion, is equal to $\frac{1}{2}MV^2$ or,

$$\tfrac{1}{2}\times\frac{1}{9{\cdot}8}\times 1000^2=51{,}000 \text{ kilogrammetres.}$$

Suppose this body to collide with a far larger perfectly rigid body moving in the same direction at one-half the speed; *i.e.* at a speed of 500 metres per second, the relative speed of the two bodies thus being $1000-500=500$ metres per second. Its motion relatively to the far larger body will, in virtue of the collision, be reversed in direction, *i.e.* relatively to the far larger body, the perfectly elastic body of one kilogram will precisely reverse its direction and will assume a velocity of 500 metres per second relatively to this far larger body. But since the larger body continues at substantially the same speed which it possessed before the collision, *i.e.* at a speed of 500 metres per second, the absolute speed of the first body has become $500-500=0$ metres per second, *i.e.* it remains motionless in space, and hence has given up its entire kinetic energy to the far larger body.[2]

Substituting the bladed rim of the revolving wheel of the

[1] It is convenient to mentally picture this body as a sphere.

[2] Our conceptions of speed can only be relative. Thus when the perfectly rigid body is itself moving with a speed V′ in the same direction as the elastic body, we should say that the perfectly elastic body, having a speed V, would collide with a relative speed of only $V-V'$, and therefore would also be repelled with a relative speed of $V-V'$. If $V'=\frac{V}{2}$ we should conclude that the elastic body is thrown back with a speed $\frac{V}{2}$ relative to the rigid body; and as the rigid body moves with an absolute speed of $\frac{V}{2}$, the absolute speed of the elastic body after the impact will necessarily be zero.

steam turbine for the "far larger body," and one kilogram of steam for the "perfectly elastic body," we at once see the basis for the statement that the speed of the blades should preferably approach one-half the speed of the impinging steam. For were this the case, and were both bodies, *i.e.* the blades and the steam, perfectly elastic, and were the steam to impinge from a direction normal to the plane of the blades at the point of impact, then the steam would be left stationary in space by the moving blade and depleted of its kinetic energy. Since the direction of impact is not normal, and since the bodies concerned are not perfectly elastic, this ideal velocity is only a rough guide; and furthermore, the present state of engineering knowledge is so limited that out of consideration for the constructional standpoint, much lower peripheral speeds are generally employed than correspond to half the speed of the impinging steam.

Total Efficiency of Conversion of Energy in Steam.

There now arise the three questions:—

I. How much energy is required to raise one kilogram of steam?

II. How great a proportion of this energy per kilogram may be converted into energy of translational motion, *i.e.*, into kinetic energy?

III. What will be the corresponding velocity of this steam?

Let us take an instance where the steam is at an absolute pressure of 13 kilograms per sq. cm. (*i.e.* 13 metric atmospheres) and with 50° Cent. of superheat. Under these conditions the total heat required to raise one kilogram of steam from one kilogram of water at 0° Cent. amounts to 698 calories (*i.e.* kilogram-degree calories).[1] To many engineers, the magnitude of this amount of energy is more readily appreciated if it is expressed by the equivalent in kilowatt-hours.

$$698 \text{ calories} = 0{\cdot}812 \text{ kilowatt-hours.}$$

For the present purpose, as we wish to arrive finally at the velocity of the steam when emerging from the mouth of the nozzle, we shall express the amount of the energy by its equivalent in kilogrammetres.

$$698 \text{ calories} = 298{,}000 \text{ kilogrammetres.}$$

Now if this energy could be transformed completely into the kinetic form (*i.e.* into energy of translational motion), then V, the

[1] This subject is dealt with in more detail in Chapter XIII.

speed of the steam in metres per second, would be derived by solving the equation:—

$$\tfrac{1}{2} \times \frac{1}{9{\cdot}8} \times V^2 = 298{,}000$$

$$\therefore \quad V = 2420 \text{ metres per second.}$$

When steam flows through plane orifices, it has been experimentally demonstrated that, independently of the ratios of the pressures on the two sides of the orifice (so long as this ratio is at least 2 : 1), and also largely independent of the contour of the orifice, the velocity of the flow of the steam through the orifice is nearly constant. It has, in fact, the values shown in the curve of Fig. 7.

From this curve we see that steam flowing from a source where the absolute pressure is 13 kilograms per sq. cm. through a plane orifice on the other side of which the pressure is 0·134 kilogram per sq. cm., *i.e.*, into a 26 in. (66 cm.) or 86·6 per cent. vacuum, will emerge from the orifice with a velocity of 450 metres per second. The kinetic energy per kilogram of steam after emerging from the orifice will be

$$\tfrac{1}{2} \times \frac{1}{9{\cdot}8} \times 450^2 = 10{,}400 \text{ kilogrammetres.}$$

This represents only $\frac{10{,}400 \times 100}{298{,}000} = 3{\cdot}48$ per cent. of the total energy per kilogram of steam at this pressure. Since, moreover, this kinetic energy is exerted in every direction, it will be liberal to estimate that not over 2 per cent. could be rendered available for imparting motion to the turbine wheel by impinging on the blades.

By de Laval's diverging nozzle, however, there is actually obtained, under those conditions of pressure, a velocity of the steam emerging from the mouth of the orifice of some 1100 metres per second, and this steam is in a state of rectilinear translational motion parallel to the axis of the nozzle. Were it not for losses due to friction against the sides of the nozzle, the velocity would be 1170 metres per second, as may be seen from the theoretical curves of Fig. 8, which have been deduced by the authors from data published by Garrison, Andersson, and Sosnowski.[1]

[1] "The de Laval Steam Turbine," Charles Garrison, *Technology Quarterly*, vol. xvii. p. 14, March 1904; "Steam Turbines, with Special Reference to the de Laval Type of Turbines," Konrad Andersson, *Transactions of the Institution of Engineers and Shipbuilders in Scotland*, vol. xlvi., November 1902; "La Turbine à Vapeur de Laval," K. Sosnowski, Paris, Imprimerie H. Cherest, 1903, p. 18.

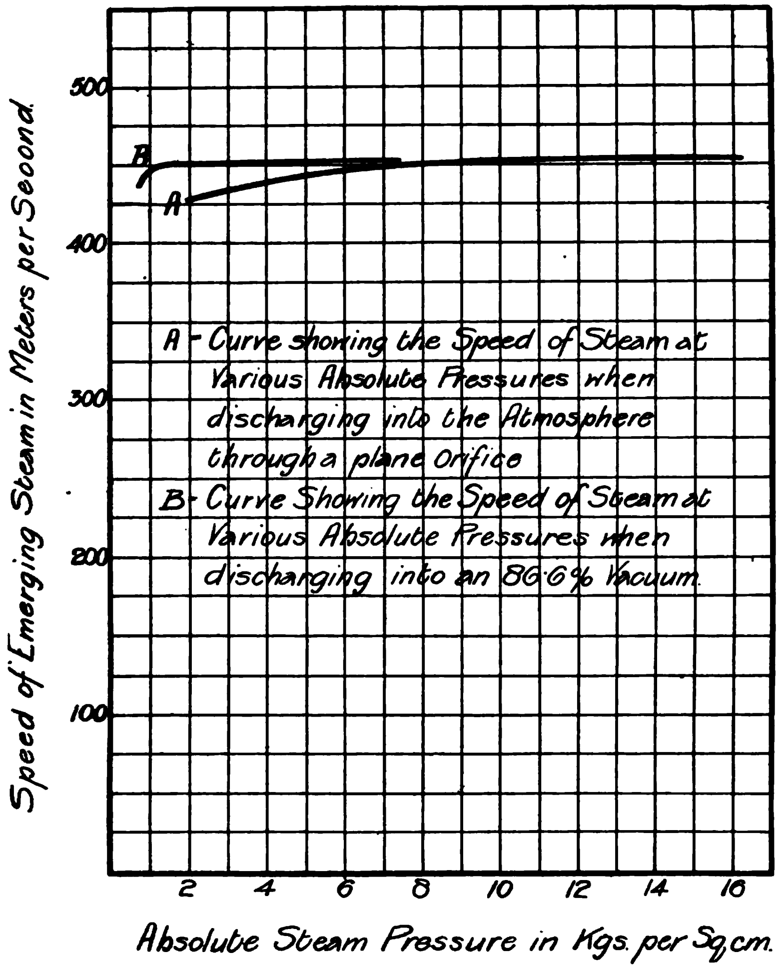


FIG. 7.

The velocity of 1100 metres per second corresponds to

$$\tfrac{1}{2} \times \frac{1}{9{\cdot}8} \times 1100^2 = 62{,}000 \text{ kilogrammetres}$$

of kinetic energy per kilogram of steam, or

$$\frac{62{,}000 \times 100}{298{,}000} = 20{\cdot}8 \text{ per cent.}$$

of the total energy necessary to raise the steam. From the relative positions and forms of the mouth of the nozzle and the blades of the turbine wheel, as shown in the right-hand illustration

Fig. 5B, and in the illustration Fig. 6, it is evident that nearly the entire kinetic energy of the steam will be directed upon the wheel. Hence, of the 0·812 kilowatt-hours of energy to raise one kilogram of steam there is applied to driving the wheel, as a maximum,

$$0{\cdot}812 \times 0{\cdot}208 = 0{\cdot}169 \text{ kilowatt-hours.}$$

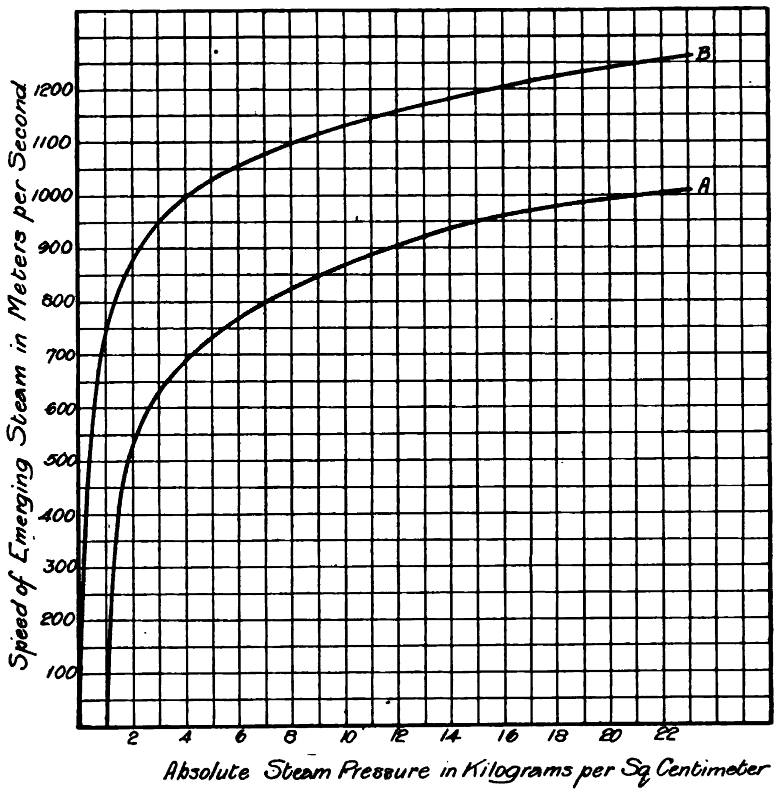


FIG. 8.—Theoretical Speeds of Steam *when discharging through suitably designed De Laval nozzles from stated pressures.*
A = *into atmosphere.*
B = *into* 86·6 *per cent. vacuum.*

For a turbine wheel of 100 per cent. efficiency, we ought, therefore, to obtain a kilowatt-hour for every

$$\frac{1}{0{\cdot}169} = 5{\cdot}9 \text{ kilograms of steam,}$$

or a brake H.P.H. for $5{\cdot}9 \times 0{\cdot}746 = 4{\cdot}4$ kilograms of steam, under the assumed conditions of an absolute admission pressure of 13 kilograms per sq. cm. and 50° C. superheat, and a condenser

pressure, of 0·134 kilograms per sq. cm., *i.e.*, an 86·6 per cent. (26 in. or 66 cm.) vacuum.

In a 300 horse-power de Laval turbine supplied with steam at an absolute pressure of 13 metric atmospheres and with 50° C. of superheat, and exhausting into a condenser with an 86·6 per cent. vacuum, a steam consumption of about 8 kilograms per brake H.P.H. is generally obtained.

When coupled to a dynamo, a 300 horse-power de Laval turbine is required for a 209 K.W. set, and when operating with an admission pressure of 13 absolute metric atmospheres, 50° C. superheat, and an 86·0 per cent. (26 in. or 66 cm.) vacuum, is found to require, at rated load, about 10 kilograms of steam per kilowatt-hour. Thus the total efficiency of conversion, from the total kinetic energy in the steam supplied, into electrical energy from the dynamo, is about $\frac{5 \cdot 9}{10} = 59$ per cent. The remaining 41 per cent. supplies the following losses:—

1. Nozzle losses.
2. Leakage losses.
3. Radiation losses.
4. Losses due to the friction of the turbine wheel revolving in the steam.
5. Losses due to the friction of the steam travelling over the vanes.
6. Losses due to the bearing friction of the wheel.
7. Losses in the speed reduction gearing.
8. Losses in the dynamo.
9. Losses due to the residual kinetic energy in the steam passing to the condenser.

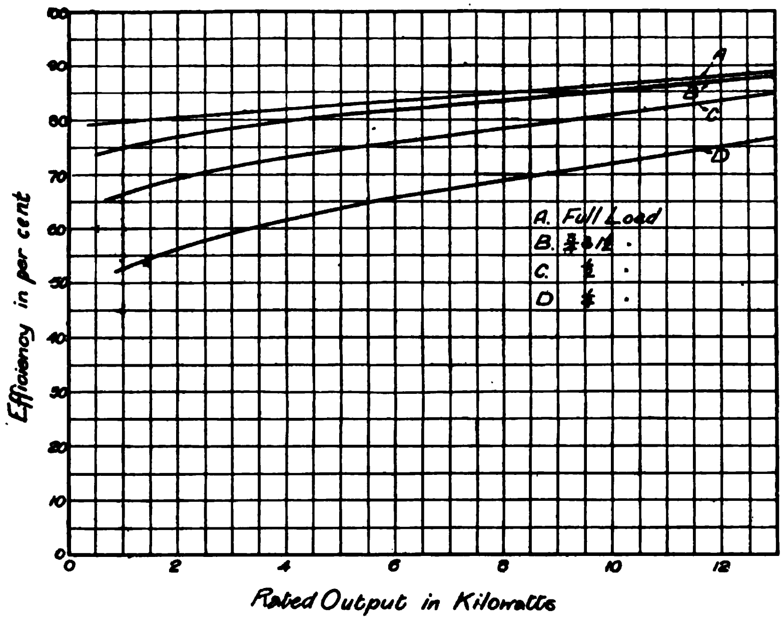
Steam Economy in De Laval Turbines

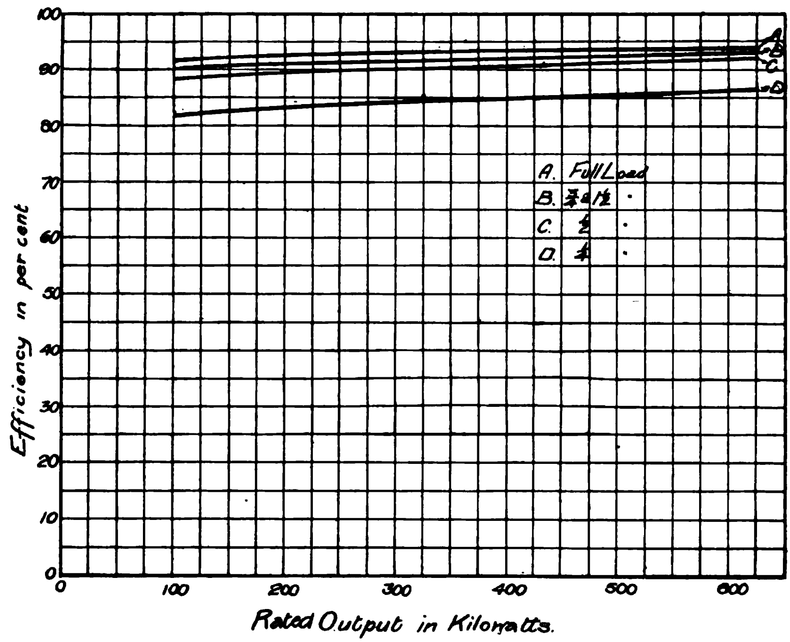
Before proceeding to discuss these internal losses, it will be of interest to investigate the steam economy obtained in practice with the de Laval steam turbine.

Throughout this section we shall adopt the practice of expressing the results in kilograms of steam per kilowatt-hour output from the dynamo driven from the turbine. Now, it is true that some of the published tests to which reference will be made, were carried out on turbines employed for purposes other than for driving dynamos. There is, of course, a wide field for such use of turbines.

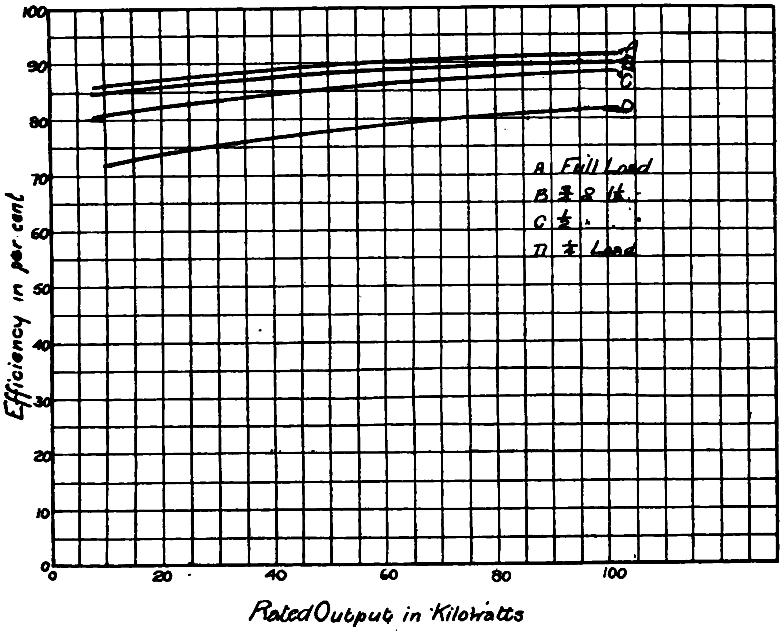
Efficiencies of Electric Generators used in Calculations.

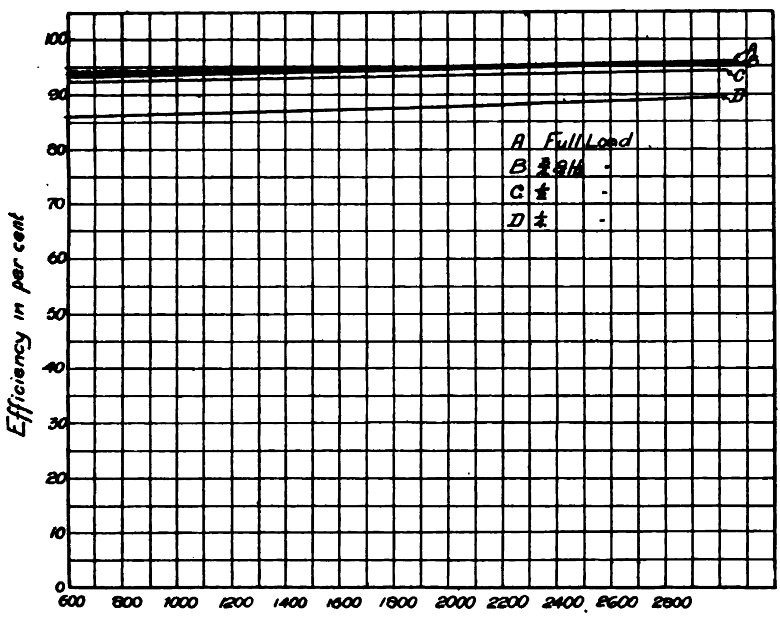
Nevertheless, since the driving of dynamos is at present by far the most extensive single application of steam turbines, we have found it desirable to reduce all results to terms of the steam



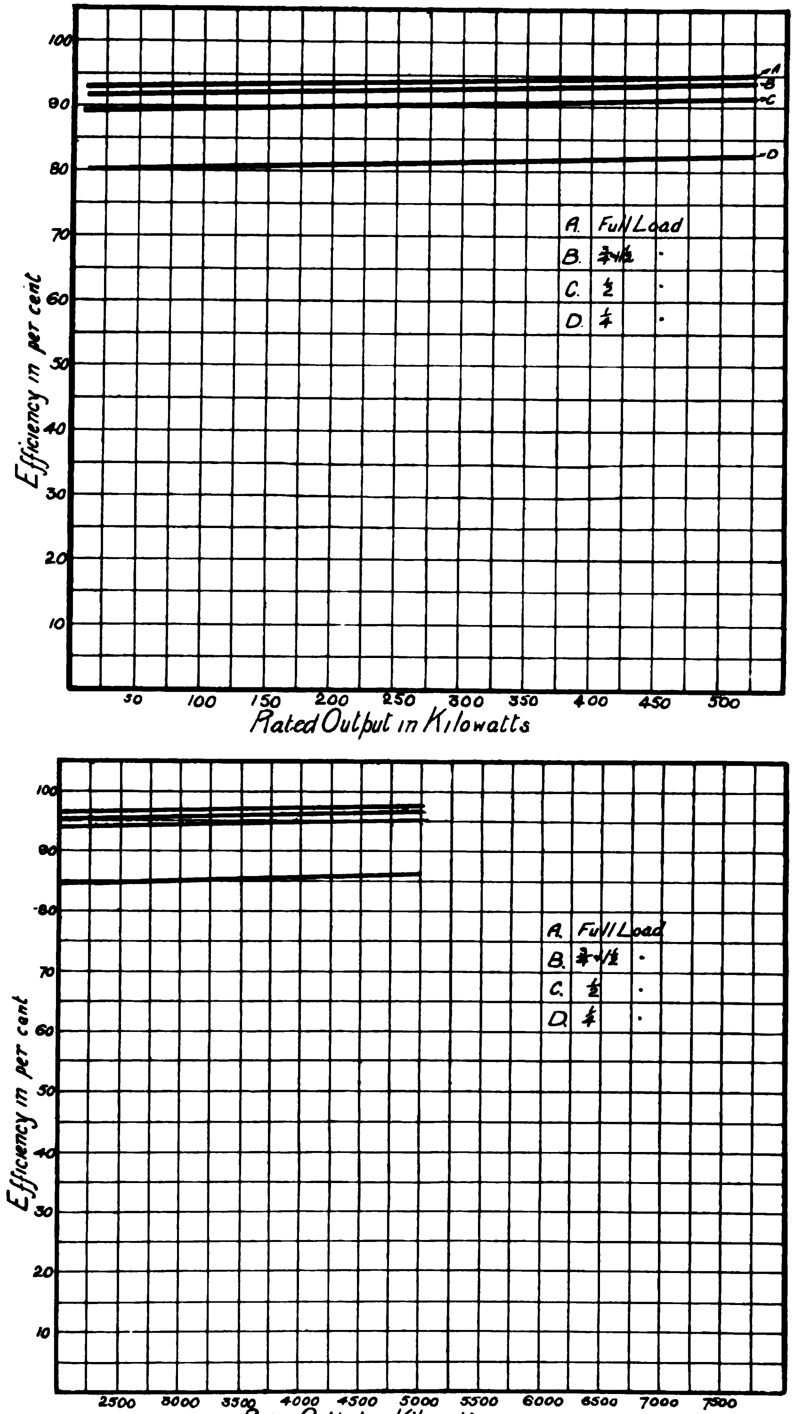


FIGS. 9 and 11.—Efficiencies *of Steam-Turbine-Driven Continuous Current* Dynamos.





Figs. 10 and 12.—Efficiencies *of Steam-Turbine-Driven Continuous Current* Dynamos.



Figs. 13 and 15.—Efficiencies of Steam-Turbine-Driven Alternators.

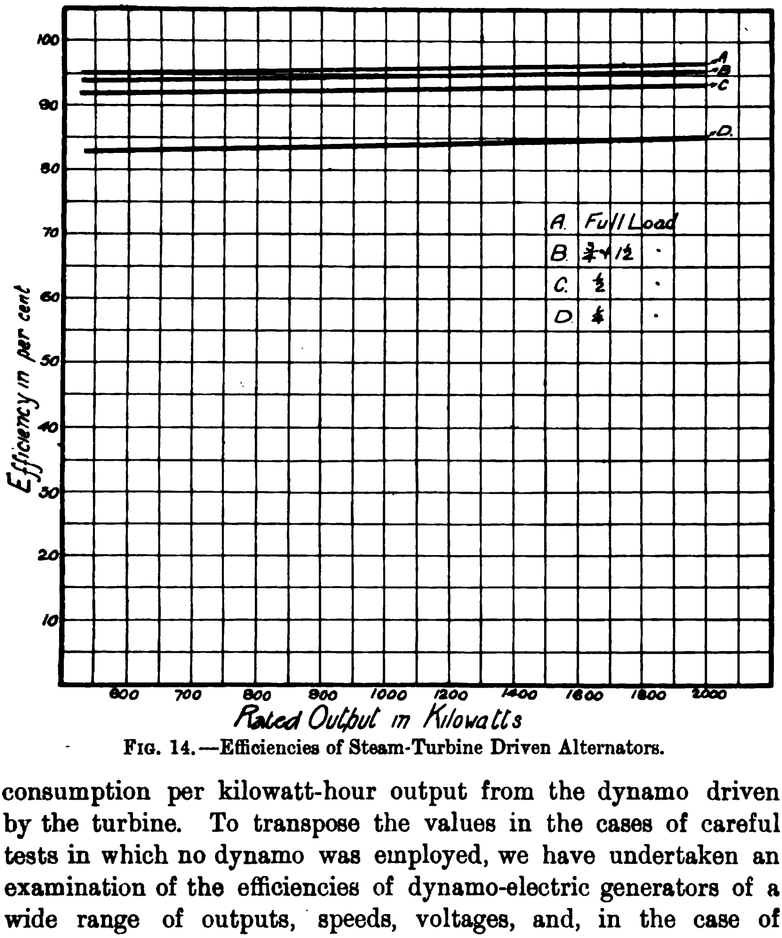
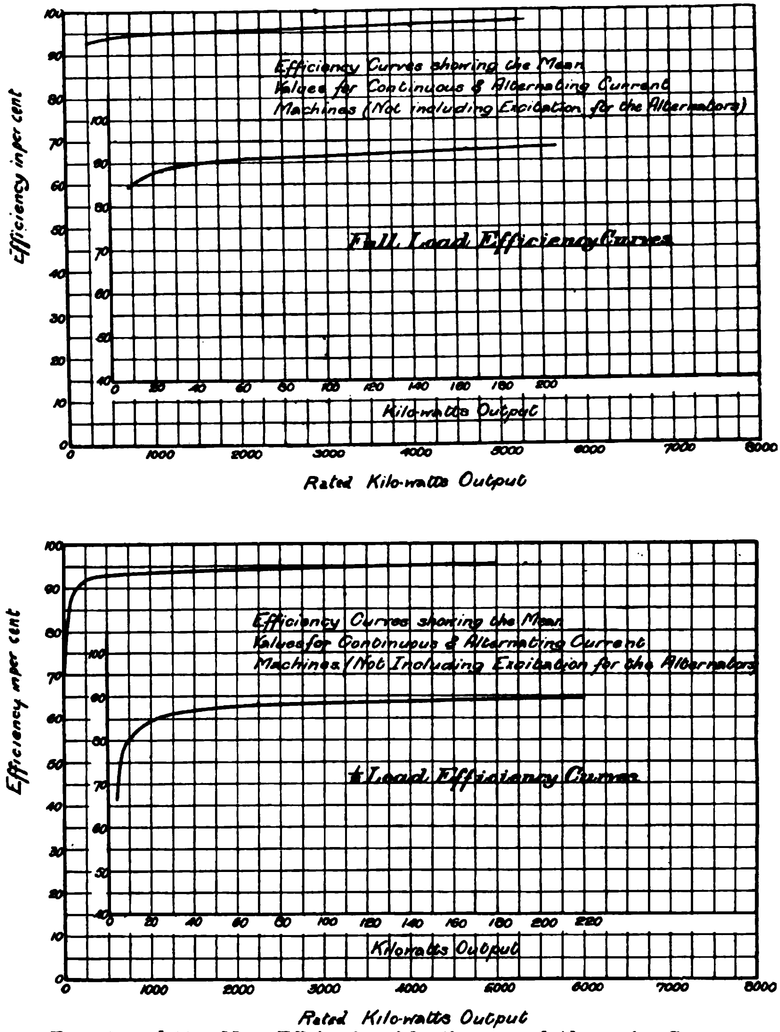


FIG. 14.—Efficiencies of Steam-Turbine Driven Alternators.

consumption per kilowatt-hour output from the dynamo driven by the turbine. To transpose the values in the cases of careful tests in which no dynamo was employed, we have undertaken an examination of the efficiencies of dynamo-electric generators of a wide range of outputs, speeds, voltages, and, in the case of polyphase generators, periodicities. The investigation comprised about 150 different machines by various firms and designers. From this data, curves were deduced setting forth, in terms of the rated output, the efficiencies at 25 per cent., 50 per cent., 75 per cent., 100 per cent., and 150 per cent. of the rated output. Obviously there is not yet sufficient progress in the design of steam turbine-driven dynamo-electric generators to obtain useful averages for the efficiencies of machines designed for these extremely high speeds, but in lieu of such information we examined at lower speeds the influence of the rated speed on the efficiencies, and we failed to find any marked uniform effect. Further progress in the art will doubtless reveal some considerable variation in the efficiencies, due to the variations in the speed,

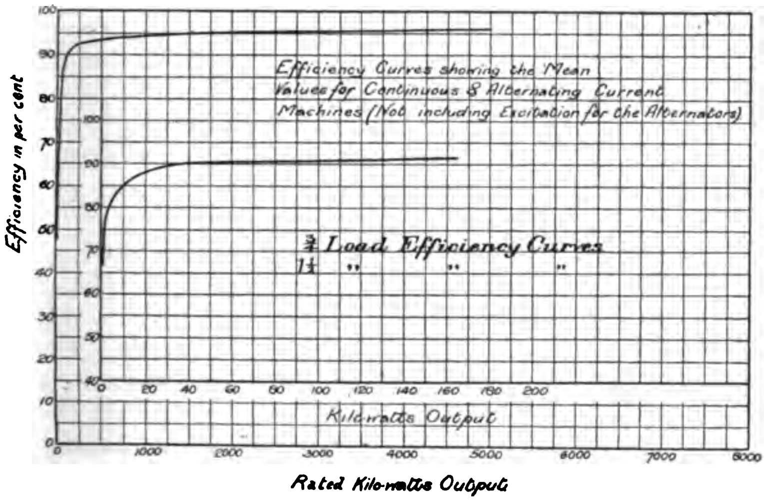
but for our present purpose we believe that the influence of the speed and frequency will rarely affect the result by more than one or two per cent. Had the results examined related exclusively

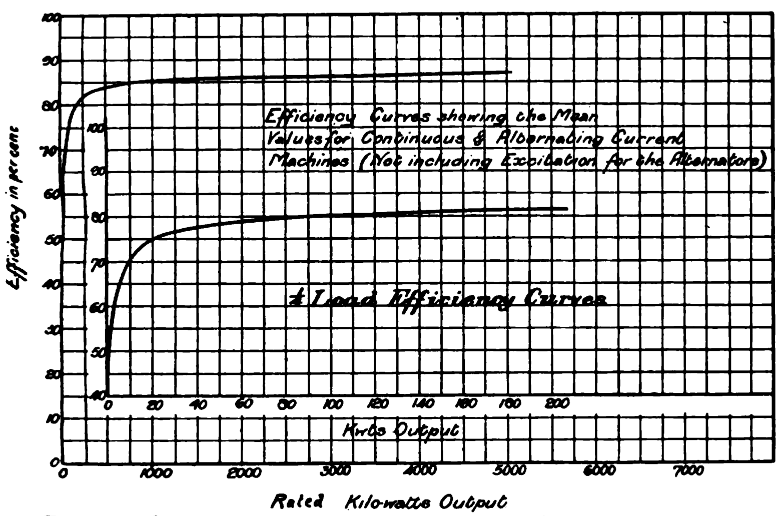


FIGS. 16 and 18.—Mean Efficiencies of Continuous and Alternating Current Generators.

to the product of one manufacturing firm or to the work of a single designer, this would not have been the case. But the curves are intended to represent average efficiencies for a large number of miscellaneous designs from many countries. Abnormal

voltages, of course, affect the results, but these are neglected in the curves, which are intended to relate to a wide range of intermediate voltages. In the case of a very high-voltage





FIGS. 17 and 19.—Mean Efficiencies of Continuous and Alternating Current Generators.

polyphase generator or a very low-voltage continuous current generator, an extra allowance should be made at the discretion of the engineer referring to these curves for any special purpose.

The results for the continuous current dynamos are set forth

in Figs. 9, 10, 11, and 12, and for the polyphase dynamos in Figs. 13, 14, and 15. In the case of the polyphase dynamos, the excitation loss has not been included in deriving the efficiencies, since the excitation will be supplied from an external source of power.

It will be seen from Figs. 9 to 15 that there is but little difference between the average results for the efficiencies of alternating current and of continuous current dynamos. For the practical purposes of the present investigation, it is more convenient to consult the curves of Figs. 16 to 19, which are mean results for alternating and continuous-current dynamos.

In all instances where the tests were made by measuring the output from the dynamo, and the input in quantity of steam, we have taken the observed results as the basis for our work and have had no occasion to consult the curves of Figs. 16 to 19. Where, however, the output from the turbine shaft alone was measured, we have assumed the addition of a dynamo having the efficiencies set forth by these curves and have deduced results for the output in kilowatt-hours from this hypothetical dynamo, per kilogram of steam consumed by the turbine.

In this way we obtained curves from which the results set forth in Table XXV. have been derived. From the curves from which we have deduced this table, we have read off the interpolated values, and this accounts for such entries as "3·7 nozzles open." Such an entry merely indicates that the load was intermediate between the loads at which 3 and 4 nozzles, respectively, were opened. Of course, each nozzle is either completely opened or completely closed.

On the basis of one or the other of the various sets of test results recorded in Table XXV. many interesting deductions may be made. See folding sheets, pages (1), (2), (3).

In Table XXVI. the German and Swedish estimates are from *Bau der Dampfturbinen*, A. Musil, Leipzig, B. G. Teubner, 1904, pp. 80 and 93. The French estimates are from "The Steam Turbine," R. H. Thurston, *Transactions, American Society of Mechanical Engineers*, vol. xxii., p. 215, 1901.

THE EFFECT OF VARYING THE PRESSURE.

Let us first concentrate our attention on the effect of varying pressure at full load.

From Test II. of Table XXV., relating to a 19·6-kilowatt set, we

TABLE

...nt. of		Results for 80 per cent. of Rated Load.					Results for 100 per cent. of Rated Load.				
Output from Dynamo.	Number of Nozzles open.	Admission Pressure (Absolute) Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Degrees Cent. Superheat at Admission.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo.	Number of Nozzles Open.	Admission Pressure (Absolute) Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Degrees Cent. Superheat at Admission.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo.	Number of Nozzles Open.
·2	1	10·90	1·0	0	29·70	1	10·90	1·0	0	28·50	1
·8	2	10·90	1·0	0	32·50	2	10·90	1·0	0	29·50	2
7	1	3·47	1·0	0	43·2	1	3·47	1·0	0	42	1
0	1	4·50	1·0	0	37·0	1	4·50	1·0	0	36	1
2	1	6·30	1·0	0	30	1	6·30	1·0	0	29	1
·6	1	8·0	1·0	0	28	1	8·0	1·0	0	27·7	1
·40	...	7	1·0	0	29·40	...	7	1·0	0	27·5	...
21	...	7	1·0	320	18·90	...	7	1·0	336	17·9	...
·0	Nos. 3 & 8	6·98	1·03	180	27·50	Nos. 3 & 8	...	...	...	...	...
30	3 & 8	6·96	1·015	196	21·50	3 & 8	...	...	...	...	...
·5	3 & 8	6·98	1·026	159	22·0	3 & 8	...	...	...	...	...

TABLE XXVI.—FULL-LOAD STEAM CONSUMPTION OF DE LAVAL STEAM TURBINE SETS IN KILOGRAMS OF DRY SATURATED STEAM PER KILOWATT-HOUR OUTPUT FROM THE DYNAMO.

Rated Output of Generator in Kilowatts.	Rated Output of Turbine in B.H.P.	Absolute Metric Atmospheres. 4									Absolute Metric Atmospheres. 5								
		German.			French.			Swedish.			German.			French.			Swedish.		
		Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%
1·83	3	58	..	..	..	..	..	..	..	..	52	..	..	..	..	..	..	..	..
3·08	5	58	31	28·5	..	..	..	..	..	..	52	30	27·7	..	..	..	..	..	..
6·20	10	51	26	24	..	..	..	..	..	..	47	25	23	..	..	..	..	..	..
9·50	15	45·6	24·8	22	..	..	..	..	..	..	41·9	23·8	21	..	..	..	..	..	..
12·9	20	48·8	21	19	..	..	..	..	..	..	43	20·6	18·6	..	..	..	..	..	..
19·6	30	43	20·5	18·5	..	..	..	..	..	..	38	19	17·7	..	..	..	..	..	..
33·3	50	42·8	18·9	17	..	..	..	..	..	..	37	18	16·5	..	..	..	..	..	..
50·3	75	39·8	18	16·5	..	..	..	..	..	..	34·6	17	16	..	..	..	..	..	..
(a)[1] 67·8	100	..	16·8	14·9	..	..	..	..	..	..	..	16	14	..	..	..	..	..	..
(b)[1] 67·8	100	39·6	18	16	..	..	..	..	..	..	33·6	17	15·8	..	..	..	..	..	..
(a)[1] 103	150	..	15·8	14	..	..	..	..	..	..	..	15	13·5	..	..	..	..	..	..
(b)[1] 103	150	36·7	..	..	..	..	..	..	..	..	31·6	..	..	..	..	..	..	..	..
137	200	..	..	.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
156	225	..	15·7	14	..	..	..	..	..	..	..	15	13	..	..	..	..	..	..
209	300	..	14·9	13·7	..	..	..	..	..	..	..	14	12	..	..	..	..	..	..

[1] The Humboldt Co. made two machines of different diameters for each of these outputs.
For the 100 horse-power Turbines diameters = (a) 500 mm. and (b) 400 mm.
" 150 " " " = (a) 500 mm. and (b) 400 mm.

TABLE XXVI.—*continued.*

Rated Output of Generator in Kilowatts.	Rated Output of Turbine in B.H.P.	Absolute Metric Atmospheres. 6									Absolute Metric Atmospheres. 7								
		German.			French.			Swedish.			German.			French.			Swedish.		
		Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%
1·83	3	48	..	..	..	..	..	..	..	..	45	..	..	43	29·2	..	..	..	..
3·08	5	48	29	27	..	..	..	..	..	..	45	28·6	26·5	36·5	26·4	..	..	..	..
6·20	10	44	24·6	22	..	..	..	..	..	..	42·7	24	21·8	36·2	22·7	..	..	..	..
9·50	15	40	23	20·8	..	..	..	..	..	..	38	22·7	20	33·8	21·3	..	..	..	..
12·9	20	40	19·8	18	..	..	..	..	..	..	37·5	19	17	32·2	17·8	..	..	..	..
19·6	30	35	18·6	17	..	..	..	..	..	..	33	18	16·6	30·0	17·6	..	..	..	..
33·3	50	33·6	17·6	16	..	..	..	..	..	..	31	17	15·7	27·7	15·5	..	..	..	..
50·8	75	31·6	16·8	15·5	..	..	..	..	..	..	29	16	15	25·7	15·1	..	..	..	..
(a)[1] 67·8	100	..	15·5	13·7	..	..	..	..	..	..	..	15	13	25·7	15·0	..	..	..	..
(b)[1] 67·8	100	29·8	16·7	15	..	..	..	..	..	..	27·6	16	15	..	..	..	..	..	..
(a)[1] 103	150	..	14·8	12·9	..	..	..	..	..	..	..	14	12·6	25·3	..	..	..	..	..
(b)[1] 103	150	28	..	..	..	..	..	..	..	..	25·9	..	..	..	..	..	..	..	..
137	200	..	..	..	..	..	..	..	..	..	..	..	..	24·0	12·6	..	..	..	..
156	225	..	14	12·5	..	..	..	..	..	..	..	13·8	12	..	..	..	..	..	..
209	300	..	13·8	11·7	..	..	..	..	..	..	..	13	11·4	23·4	12·3	..	..	..	..

[1] The Humboldt Co. made two machines of different diameters for each of these outputs.
For the 100 horse-power Turbines diameters = (a) 500 mm. and (b) 400 mm.
" 150 " " " = (a) 500 mm. and (b) 400 mm.

TABLE XXVI.—*continued.*

Rated Output of Generator in Kilowatts.	Rated Output of Turbine in B.H.P.	Absolute Metric Atmospheres. 8									Absolute Metric Atmospheres. 9								
		German.			French.			Swedish.			German			French.			Swedish.		
		Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%
1·83	3	43	..	..	..	..	..	..	..	..	41·7	..	..	39·4	29·2	..	..	..	..
3·08	5	43	28	25·9	..	..	..	..	..	..	41	27·6	25·6	34·0	25·5	..	..	..	..
6·20	10	41	23·5	21	..	..	..	..	..	..	39	23	20·8	33·8	21·8	..	..	..	..
9·50	15	36·5	22	20	..	..	..	..	..	..	35	21·8	19·7	31·1	20·6	..	..	..	..
12·9	20	35·5	18·7	17	..	..	..	..	..	..	33·9	18	16·7	29·7	17·2	..	..	..	..
19·6	30	31·5	17·6	16	..	..	..	..	..	..	30	17	16	27·7	16·9	..	..	..	..
33·3	50	29·7	16·6	15	..	..	..	..	..	..	28·5	16	15	25·4	14·7	..	..	..	..
50·8	75	27·8	16	14·9	..	..	..	..	..	..	26·6	15·8	14·6	23·7	14·3	..	..	..	..
(a)[1] 67·8	100	..	14·6	13	..	..	..	..	..	..	..	14	12·7	23·5	13·3	..	..	..	..
(b)[1] 67·8	100	25·8	16	14·8	..	..	..	..	..	..	24·6	15·6	14	..	..	..	..	..	..
(a)[1] 103	150	..	14	12	..	..	..	..	..	..	..	13·7	13	23·3	..	..	..	..	..
(b)[1] 103	150	24	..	..	..	..	..	..	..	..	23	..	..	..	..	..	..	..	..
137	200	..	..	..	..	..	..	..	..	..	..	..	..	21·9	12·0	..	..	..	..
156	225	..	13	11·9	..	..	..	..	..	..	..	13	11·6	..	..	..	..	..	..
209	300	13	11	..	..	..	..	..	..	..	..	12·7	10·8	20·8	11·85	..	..	..	..

[1] The Humboldt Co. made two machines of different diameters for each of these outputs
For the 100 horse-power Turbines diameters = (a) 500 mm. and (b) 400 mm.
" 150 " " " = (a) 500 mm. and (b) 400 mm.

TABLE XXVI.—*continued.*

Rated Output of Generator in Kilowatts.	Rated Output of Turbine in B.H.P.	Absolute Metric Atmospheres. 10									Absolute Metric Atmospheres. 11								
		German.			French.			Swedish.			German.			French.			Swedish.		
		Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%
1·88	3	40	..	..	..	..	..	..	..	..	39	..	..	37·4	27·1	..	..	..	..
3·08	5	40	27	25	.	..	..	..	..	..	39	26·7	25	32·0	24·8	..	..	..	..
6·20	10	37·8	22·7	20·5	..	..	..	..	..	..	36	22	20	31·8	21·2	..	..	..	..
9·50	15	33·5	21	19	..	..	..	..	..	..	32	21	19	29·4	19·9	..	..	..	..
12·9	20	32	18	16	..	..	..	..	..	..	31	17·8	16	27·8	16·8	..	..	..	..
19·6	30	29	17	15·6	..	..	..	..	..	..	28	16·7	15	26·1	16·3	..	..	..	..
33·3	50	27·8	16	14·8	..	..	..	24·7	14·4	12·85	27	15·9	14·5	24·0	14·2	..	24	14·2	12·6
50·8	75	25·8	15·5	14	..	..	..	..	..	..	25	15	14	22·0	13·9	..	..	..	..
(a)[1] 67·8	100	..	14	12·5	..	..	..	22·8	14·1	12·55	..	13·7	12	22·0	12·8	..	22·2	13·85	12·3
(b)[1] 67·8	100	23·9	15	14	..	..	..	..	..	..	23	15	13·9	..	..	..	..	..	..
(a)[1] 103	150	..	13	12	..	..	..	..	..	..	..	13	11·9	21·8	..	..	..	..	..
(b)[1] 103	150	22	..	..	..	..	..	..	..	..	21·8	..	..	..	..	..	..	..	..
137	200	..	..	..	..	..	..	..	11·95	..	..	..	..	21·1	11·5	..	..	11·7	..
156	225	..	12·8	11	..	..	..	..	..	..	..	12·6	11	..	..	..	..	..	..
209	300	..	12	10·6	..	..	..	..	11·4	..	..	12	10	19·7	11·2	..	..	11·05	..

[1] The Humboldt Co. made two machines of different diameters for each of these outputs.
For the 100 horse-power Turbines diameters = (a) 500 mm. and (b) 400 mm.
" 150 " " " = (a) 500 mm. and (b) 400 mm.

TABLE XXVI.—*continued.*

Rated Output of Generator in Kilowatts.	Rated Output of Turbine in B.H.P.	Absolute Metric Atmospheres. 12									Absolute Metric Atmospheres. 13								
		German.			French.			Swedish.			German.			French.			Swedish.		
		Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%
1·83	3	38·5	..	..	..	..	..	..	..	..	37·7	..	..	35·5	26·4	..	..	..	..
3 08	5	38	26	25	..	..	..	..	..	..	37·5	26	24·8	30·5	24·2	..	..	..	..
6·20	10	34·6	22	20	..	..	..	..	..	..	33	21·7	20	30·3	20·3	..	..	..	..
9·50	15	31	20·6	18·9	..	..	.	..	..	..	30	20	18·7	28·1	19·4	..	..	..	..
12·9	20	30	17·6	16	..	..	..	..	..	..	28·6	17·5	15·9	26·9	16·1	..	..	..	..
19 6	30	27	16·6	15	..	..	..	..	..	..	26·8	16	15	24·8	15 8	..	..	..	..
33·3	50	26	15·7	14	..	..	..	23·3	14·0	12·45	25·6	15·6	14	22·8	13 75	..	22·7	13·8	12·3
50·8	75	24	15	13·8	..	..	..	..	..	..	23·8	15	13·7	21·0	13·5	..	..	..	..
(a)[1] 67·8	100	..	13·6	12	..	..	..	20·8	13·65	12·2	..	13	12	20·4	12·4	..	21·0	13·45	12·05
(b)[1] 67·8	100	22	15	13 7	..	..	..	..	..	..	21·8	14·9	13·6	..	..	..	..	..	..
(a)[1] 103	150	..	12·9	11·7	..	..	..	..	..	..	..	12·8	11·6	20·3	..	..	..	..	..
(b)[1] 103	150	21	..	..	..	..	..	..	..	..	20	..	..	..	..	..	..	..	..
137	200	..	..	..	..	..	..	..	11·5	..	..	..	..	20·0	11·3	..	..	11·4	..
156	225	..	12	11	..	..	..	..	..	..	..	12	11	...	..	..	..	..	..
209	300	..	11·8	10	..	..	..	..	11·0	..	..	11·8	10	18·6	10·9	..	..	10·85	..

[1] The Humboldt Co. made two machines of different diameters for each of these outputs.
For the 100 horse-power Turbines diameters = (a) 500 mm. and (b) 400 mm.
,, 150 ,, ,, ,, = (a) 500 mm. and (b) 400 mm.

TABLE XXVI.—*continued.*

Rated Output of Generator in Kilowatts.	Rated Output of Turbine in B.H.P.	Absolute Metric Atmospheres 14									Absolute Metric Atmospheres. 15								
		German.			French.			Swedish.			German.			French.			Swedish.		
		Non-condensing	Vacuum of		Non-condensing.	Vacuum of		Non-condensing.	Vacuum of		Non-condensing.	Vacuum of		Non-condensing.	Vacuum of		Non-condensing.	Vacuum of	
			84%	92%		84%	92%		84%	92%		84%	92%		84%	92%		84%	92%
1·83	3	36·8	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	..
3·08	5	36·6	25·7	24·8	..	..	..	..	..	..	35·8	25·5	24·5	..	..	..	..	..	..
6·20	10	31	21	19·9	..	..	..	..	..	..	29 6	21	19·6	..	..	..	..	..	..
9·50	15	28·8	20	18·5	..	..	..	..	..	..	27·8	19·6	18	..	..	..	..	..	..
12·9	20	27 6	17	15·7	..	..	..	..	..	..	26·8	17	15·6	..	..	..	..	..	..
19·6	30	26	16	14·9	..	..	..	..	..	..	25·6	16	14·7	..	..	..	..	..	..
33·3	50	25	15	14	..		..	..	..	..	24	15	12·9	..	..	..	..	..	..
50·8	75	23	14·9	13·5	..	..		..	..	..	22·6	14·7	13	..	..	..	..	..	..
(a)[1] 67·8	100	..	13	12	..	..	..	..	..	..	..	13	11·8	..	..	..	..	..	..
(b)[1] 67·8	100	21	14·8	13	..	..	..	..	..	..	20·7	14·6	13	..	..	..	..	..	..
(a)[1] 103	150	..	12·7	11	..	..	..	..	..	..	..	12·5	11	..	..	..	..	..	..
(b)[1] 103	150	19·8	..	..	..	..	..	..	..	..	19	..	..	..	..	..	..	..	..
137	200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
156	225	..	12	10·7	..	..	..	..	..	..	..	12	10·6	..	..	..	..	..	..
209	300	..	11·5	10	..	..	..	..	..	..	..	11	10	..	..	..	..	..	..

[1] The Humboldt Co. made two machines of different diameters for each of these outputs.
For the 100 horse-power Turbines diameters = (a) 500 mm. and (b) 400 mm.
" 150 " " " = (a) 500 mm. and (b) 400 mm.

TABLE XXVI.—*continued.*

Rated Output of Generator in Kilowatts.	Rated Output of Turbine in B.H.P.	Absolute Metric Atmospheres. 16									Absolute Metric Atmospheres. 17								
		German.			French.			Swedish.			German.			French.			Swedish.		
		Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%
1·33	3	35·5	..	..	..	..	..	..	..	..	..	..	..	33·5	25·5	..	..	..	..
3·08	5	35	25	24	..	..	..	..	..	..	..	..	..	29·0	23·2	..	..	..	..
6·20	10	28·8	20·7	19	..	..	..	..	..	..	..	..	..	28·8	19·7	..	..	..	..
9·50	15	26·9	19	18	..	..	..	..	..	..	..	..	..	26·7	18·65	..	..	..	..
12·9	20	26	16·9	15	..	..	..	..	..	..	..	..	..	25·3	15·4	..	..	..	..
19·6	30	25	16	14·6	..	..	..	..	..	..	..	..	..	23·3	15·1	..	..	..	..
33·3	50	24	15	13·7	..	..	..	..	..	..	..	..	..	21·2	13·3	..	..	..	..
50·8	75	22	14·5	13	..	..	..	..	..	..	..	..	..	19·5	13·0	..	..	..	..
(a)[1] 67·8	100	..	13	11·6	..	..	..	..	..	..	..	..	..	19·5	12·0	..	..	..	..
(b)[1] 67·8	100	20	14·5	13	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
(a)[1] 103	150	..	12	11	..	..	..	..	..	..	..	..	..	19·4	..	..	..	..	..
(b)[1] 103	150	19	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
137	200	..	..	..	..	..	..	..	..	..	..	..	..	18·6	11·1	..	..	..	..
156	225	..	11·8	10·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
209	300	..	11	10	..	..	..	..	..	..	..	..	..	17·2	10·6	..	..	..	..

[1] The Humboldt Co. made two machines of different diameters for each of these outputs.
For the 100 horse-power Turbines diameters = (*a*) 500 mm. and (*b*) 400 mm.
" 150 " " " = (*a*) 500 mm. and (*b*) 400 mm.

Table XXVI.—*continued.*

Rated Output of Generator in Kilowatts.	Rated Output of Turbine in B.H.P.	Absolute Metric Atmospheres. 18									Absolute Metric Atmospheres. 19								
		German.			French.			Swedish.			German.			French.			Swedish.		
		Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%
1·83	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3·08	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
6·20	10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
9·50	15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
12·9	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
19·6	30	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
33·3	50	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
50·8	75	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
(a)[1] 67·8	100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
(b)[1] 67·8	100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
(a)[1] 103	150	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
(b)[1] 103	150	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
137	200	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
156	225	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
209	300	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

[1] The Humboldt Co. made two machines of different diameters for each of these outputs.
For the 100 horse-power Turbines diameters =(*a*) 500 mm. and (*b*) 400 mm.
,, 150 ,, ,, ,, =(*a*) 500 mm. and (*b*) 400 mm.

TABLE XXVI.—*continued.*

Rated Output of Generator in Kilowatts.	Rated Output of Turbine in B.H.P.	Absolute Metric Atmospheres. 20									Absolute Metric Atmospheres. 21								
		German			French.			Swedish.			German.			French.			Swedish.		
		Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%	Non-condensing.	Vacuum of 84%	Vacuum of 92%
1·83	3	..	..	..	..	..	..	..	..	..	..	..	..	32·7	24·2	..	..	..	..
3·08	5	..	..	..	..	.	..	..	..	..	..	..	..	28·1	22·3	..	..	..	..
6·20	10	..	..	..	..	..	..	..	..	..	..	..	..	27·9	19·2	..	..	..	..
9·50	15	..	..	..	..	..	..	..	..	..	..	..	..	25·7	18·2	..	..	..	..
12·9	20	..	..	..	..	..	..	..	..	..	..	..	..	24·5	14·9	..	..	..	..
19·6	30	..	..	..	..	..	..	..	..	..	..	..	..	22·7	14·7	..	..	..	..
33·3	50	..	.	..	..	..	..	..	..	..	..	..	..	19·6	13·0	..	..	..	..
50·8	75	..	..	..	..	..	..	..	..	..	..	..	..	18·5	12·7	..	..	..	..
(a)[1] 67·8	100	..	..	..	..	..	..	..	..	..	..	..	..	18·4	11·6	..	..	..	..
(b)[1] 67·8	100	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
(a)[1] 103	150	..	..	..	..	..	..	..	..	..	..	..	..	18·1	..	..	..	..	..
(b)[1] 103	150	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
137	200	..	..	..	..	..	..	..	..	..	..	..	..	17·6	10·8	..	..	..	..
156	225	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
209	300	..	..	..	..	..	..	..	..	..	..	..	..	16·5	10·4	..		..	..

[1] The Humboldt Co. made two machines of different diameters for each of these outputs.
For the 100 horse-power Turbines diameters = (*a*) 500 mm. and (*b*) 400 mm.
" 150 " " " = (*a*) 500 mm. and (*b*) 400 mm.

obtain curve A of Fig. 20, showing the relation between admission pressure and steam consumption when operating non-condensing. Curve B, of the same figure, is deduced from the values in Table XXVI., which sets forth the guarantees of three of the companies manufacturing the de Laval turbine. Incidentally, the curves of Fig. 20 indicate that these guarantees are conservative, as they show for this size of turbine slightly higher steam consumptions than were found by tests. For our present purpose, however, it is the rate of change of the full load consumption with change in admission pressure which we wish to study, and we shall therefore take mean values between the two curves A and B. We thus derive Table XXVII.

TABLE XXVII.—ANALYSIS OF THE TEST RESULTS FOR A 19·6 K.W. DE LAVAL TURBINE FOR THE PURPOSE OF DETERMINING THE RELATION BETWEEN ADMISSION PRESSURE AND STEAM CONSUMPTION, WHEN RUNNING NON-CONDENSING.

Change in Admission Pressure in (Absolute) Metric Atmospheres from I. to II.		Corresponding Percentage Decrease in Steam Consumption from Fig. 20.	Corresponding Percentage Decrease in Steam Consumption for each per cent. Increase in Pressure.	Corresponding Mean Pressure in (Absolute) Metric Atmospheres (*i.e.* Mean of I. and II.).
I.	II.			
2	3	23·0	0·46	2·50
3	4·5	22·0	0·44	3·75
4	6	21·0	0·42	5·00
5	7·5	17·9	0·358	6·25
6	9	13·35	0·267	7·50
7	10·5	10·7	0·214	8·75
8	12	10·9	0·218	10·00
9	13·5	10·4	0·208	11·25
10	15	10·0	0·20	12·50
11	16·5	10·2	0·204	13·75

The results in the last two columns of Table XXVII. are plotted in curve A of Fig. 21. From the Humboldt Company's guarantee tables we have also deduced curve B for these same pressures, but with the accompaniment of a vacuum of 86·6 per cent. (26 inches or 660 millimetres).

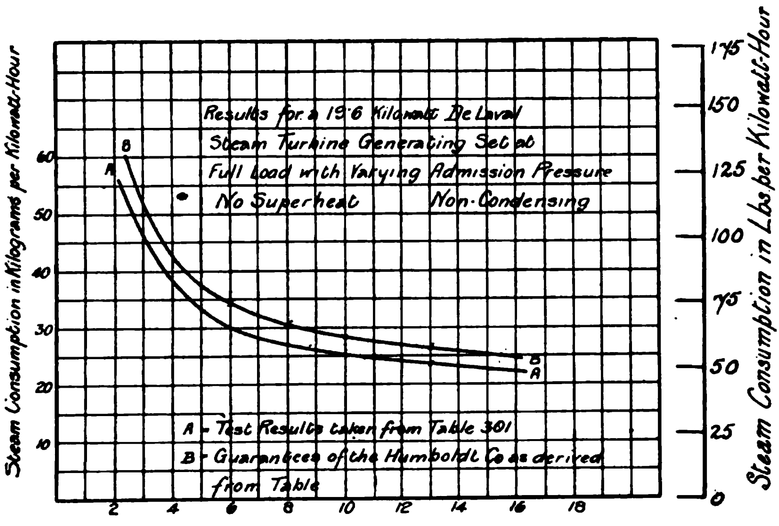


FIG. 20.—Steam Consumption 19·6 K.W. De Laval Set.
(*From Table XXVI.*)

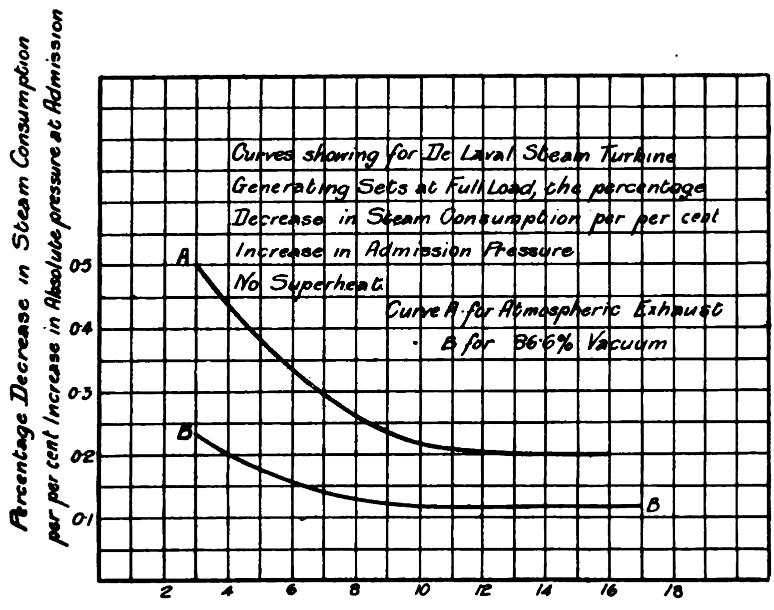


FIG. 21.—Effect of Pressure on Steam Consumption.

For the lower pressures these curves should only be used for small changes of pressure,—say, not more than two atmospheres.

By comparing the Humboldt Company's guarantees for their larger sizes of de Laval turbine, the same rate of decrease in steam consumption per per cent. increase in admission pressure is found to obtain, and hence at full load the curves of Fig. 21 may be taken as correct not only for the 19·6 kilowatt size, but for all sizes of de Laval steam turbine generating sets up to the largest on their lists, which has a full-load rating of 209 kilowatts.

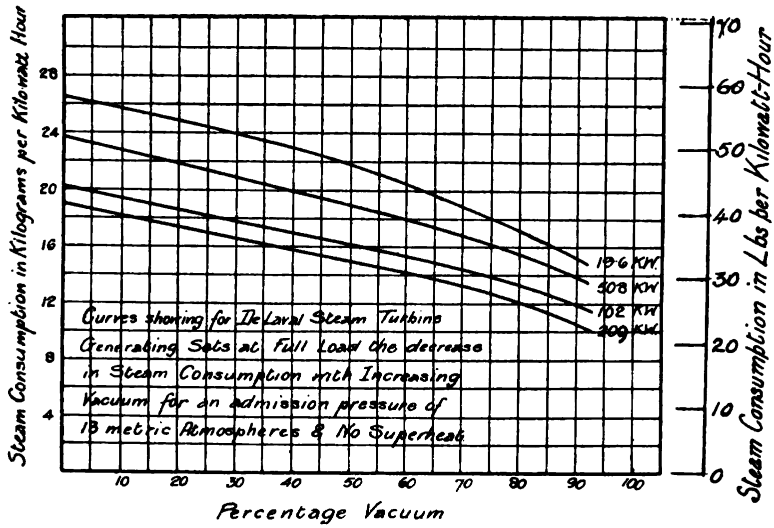
The Effect of Varying the Vacuum.

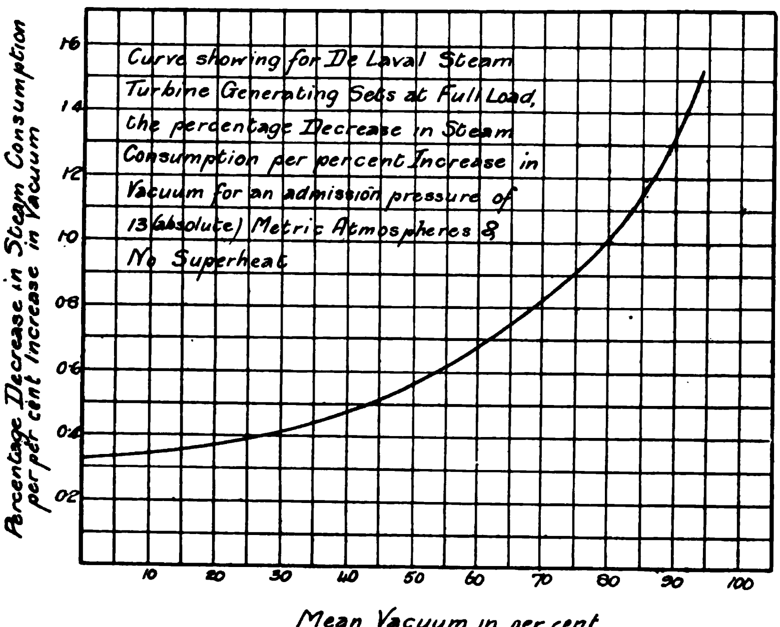
The next point is to study, at full load, the decrease in steam consumption per per cent. increase in vacuum. We shall at first confine our investigation to an admission pressure of 13 (absolute) metric atmospheres and no superheat, and we shall base our study upon the values guaranteed by the Humboldt Company as given in Table XXVI.

Analysing these guarantees at a pressure of 13 (absolute) metric atmospheres and no superheat, for sets of 19·6, 50·8, 102 and 209 kilowatts capacity, we obtain the curves of Fig. 22. These all show approximately the percentage decrease in steam consumption per per cent. increase in vacuum, plotted in the curve of Fig. 23.

Now by first applying corrections for different pressures and next for different vacua, we are in a position to reduce any observed full-load results to terms of the performance of a set of corresponding rated output, but designed for and operated at an admission pressure of 13 (absolute) metric atmospheres, and with a vacuum of 86·6 per cent. (26 inches or 660 millimetres for a barometric pressure of 30 inches or 760 millimetres), and with no superheat. By this means we derive from the full-load data in Table XXV. the values set forth in Section A of Table XXVIII., in which have also been entered up for the corresponding sizes the values taken from the guarantee lists of the French, German, and Swedish de Laval companies.

Thus from the data under the heading of Reference No. I. of Table XXV. we see that Lea and Meden found 29 kilograms per kilowatt-hour to be the steam consumption of a 10 kilowatt set at full load, for an admission pressure of 11 (absolute) metric atmospheres, no superheat, and working non-condensing. From Fig. 21 we find that a turbine working under the same conditions in all other respects, but with an admission pressure of 13 (absolute) metric atmospheres instead of 11, will have its steam consumption reduced 0·21 per cent. for each per cent. increase in





FIGS. 22 and 23.—Effect of Vacuum on Steam Consumption.

steam pressure. This value is derived from curve A for the mean steam pressure of

$$\frac{11+13}{2}=12 \text{ (absolute) metric atmospheres.}$$

Now an increase from 11 to 13 atmospheres is an increase of

$$\frac{13-11}{11} \times 100 = 18{\cdot}2 \text{ per cent.}$$

Hence the improvement in economy will be

$$18{\cdot}2 \times 0{\cdot}21 = 3{\cdot}8 \text{ per cent.},$$

and the steam consumption will be reduced to

$$29{\cdot}0 \times 0{\cdot}96 = 27{\cdot}9 \text{ kilograms per kilowatt-hour.}$$

In all cases where the change in pressure is a matter of but a few atmospheres, it suffices to thus employ the mean percentage increase as obtained from the curves in Fig. 21.

Now what will be the economy when we introduce the further change from working non-condensing to working with 86·6 per cent. vacuum? In this case the change is rather too great to make it desirable to employ the rate of change at the mean value of the vacuum (*i.e.* at 43·3 per cent. vacuum), as obtained from Fig. 23. It is preferable to consult the curves in Fig. 22, from all four of which we find that the steam consumption with a vacuum of 86·6 per cent. is approximately 61 per cent. of the consumption when working non-condensing, or, over this wide range, the average rate of decrease in steam consumption for each per cent. increase in vacuum is

$$\frac{100-61}{86{\cdot}6} = 0{\cdot}45 \text{ per cent.}$$

Full-Load Steam Consumption.

Hence the full-load steam consumption of a 19·6-kilowatt turbo set for operation at a pressure of 13 (absolute) metric atmospheres and with an 86·6 per cent. vacuum, will be

$$27{\cdot}9 \times 0{\cdot}61 = 17{\cdot}0 \text{ kilograms per kilowatt-hour.}$$

This is the value entered up under reference No. I. in section A of Table XXVIII. In the same way, by derivation from the full-load test results in Table XXV. we have obtained values for the remaining sizes at full load for these same admission and exhaust pressures, and these have been embodied in the appropriate section of Table XXVIII. The full-load values in section A of Table XXVIII. have been plotted in Fig. 24, which shows the steam consumption at full-rated load for various rated outputs, at an absolute pressure of 13 kilograms, 86·6 per cent. vacuum and no superheat. The

TABLE XXVIII.—NO SUPERHEAT.

Reference Number from Table XXV.	Rated Output reduced to terms of Kilowatts from Dynamo at Rated Load.	Rated Speed of Turbine in Revolutions per Minute.	Speed of Dynamo in Revolutions per Minute.	Ratio of Gearing.	A. Steam Consumption of the De Laval Steam Turbine at Various Loads per K.W. Hour Output at 13 Absolute Metric Atmospheres, with an 86·6 per cent. Vacuum. No Superheat. (Full Load.) As derived from Test Results in Table XXV.	(Full Load.) As derived from French Co.'s Guarantee List.	(Full Load.) As derived from German Co.'s Guarantee Lists.	(Full Load.) As derived from Swedish Co.'s Guarantee Lists.	(Half Load.) As derived from Test Results in Table XXV.	(Quarter Load.) As derived from Test Results in Table XXV.
I.	10	24,000	2400	10 : 1	17·0	[1] 19·3	19·2	..	22·0	..
II.	19·6	20,000	2000	10 : 1	15·7	[1] 15·8	15·5	..	16·8	19·5
III.	19·6	20,000	2000	10 : 1	13·8	[1] 15·8	15·5	..	18·6	21·7
IV.	19·6	20,000	2000	10 : 1	14·7	[1] 15·8	15·5	..	18·6	26·0
V.	37·4	..	..	..	14·4	[1] 13·9	14·6	13·1	16·1	17·85
VI.	37·4	..	..	..	14·65	[1] 13·9	14·6	13·1	15·9	17·7
VII.	74·6	13,000	1250	10 : 1	12·6	[1] 12·3	12·4	12·5	13·4	14·7
VIII.	103	..	..	..	10·2	[1] 12·0	12·1	12·1	12·3	14·5
IX.	103	13,000	1050	12·5 : 1	10·2	[1] 12·0	12·1	12·1	12·0	14·5
X.	137	..	900	..	9·6	[1] 11·4	11·7	11·6	12·7	..
XI.	200	..	749	..	11·1	[1] 10·9	11·0	11·4[1]	12·5	14·4
XII.	..	..	..	..	..	..	..	..	..	..
XIII.	..	..	..	..	..	..	..	..	..	..
XIV.	..	..	..	..	..	..	..	..	..	..
XV	209	10,600	749	14 : 1	10·6	[1] 11·0	10·8	11·0[1]	12·1	14·1
XVI.	..	..	..	..	..	..	..	..	..	..
XVII.	209	10,500	900	12 : 1	10·7	[1] 11·0	10·8	11·0[1]	12·4	..
XVIII.	209	7500	770	10 : 1	10·1	[1] 11·0	10·8	11·0	11·5	13·0
XIX.	209	7500	750	10 : 1	10·1	[1] 11·0	10·8	11·0	11·2	12·7
XX.	..	..	..	..	..	..	..	..	..	..

[1] Guaranteed for an 84 per cent. vacuum.

TABLE XXVIII.—50° C. SUPERHEAT.

Reference Number from Table XXV.	Rated Output reduced to terms of Kilowatts from Dynamo at Rated Load.	Rated Speed of Turbine in Revolutions per Minute.	Speed of Dynamo in Revolutions per Minute.	Ratio of Gearing.	B. Steam Consumption of the De Laval Steam Turbine at Various Loads per K.W. Hour Output at 13 Absolute Metric Atmospheres and an 86·6 per cent. Vacuum. 50° C. Superheat.					
					Full Load.				Half Load.	Quarter Load.
					As derived from Test Results in Table XXV.	As derived from French Co.'s Guarantee List, altered only for Superheat.	As derived from German Co.'s Guarantee List, altered only for Superheat.	As derived from Swedish Co.'s Guarantee Lists, altered only for Superheat.	As derived from Test Results in Table XXV.	As derived from Test Results in Table XXV.
I.	10	24,000	2400	10 : 1	15·8	[1] 17·9	17·8	..	20·4	..
II.	19·6	20,000	2000	10 : 1	15·7	[1] 14·65	14·4	..	14·65	18·1
III.	19·6	20,000	2000	10 : 1	12·3	[1] 14·65	14·4	..	17·3	20·0
IV.	19·6	20,000	2000	10 : 1	13·6	[1] 14·65	14·4	..	17·3	20·0
V.	37·4	..	..	..	13·4	[1] 12·9	13·55	12·2	14·95	16·55
VI.	37·4	..	..	..	13·6	[1] 12·9	13·55	12·2	14·75	16·4
VII.	74·6	13,000	1250	10 : 1	11·7	[1] 11·4	11·5	11·6	12·45	13·6
VIII.	103	..	..	..	9·5	[1] 11·1	11·2	11·2	11·4	13·45
IX.	103	13,000	1050	12·5 : 1	9·5	[1] 11·1	11·2	11·2	11·15	13·45
X.	137	..	900	..	8·9	[1] 10·6	10·85	10·75	11·8	..
XI.	200	..	749	..	10·3	[1] 10·1	10·2	10·6	11·6	[1] 13·35
XII.	..	..	..	..	9·7	[1] 10·1	10·2	10·6	10·2	..
XIII.	..	..	..	..	9·2	[1] 10·1	10·2	10·6	10·3	12·0
XIV.	..	..	..	..	9·4	[1] 10·1	10·2	10·6	10·75	12·25
XV.	209	10,600	749	14 : 1	9·85	[1] 10·2	10·0	10·2	11·25	[1] 13·05
XVI.	..	..	..	..	9·65	[1] 10·2	10·0	10·2	11·8	..
XVII.	209	10,500	900	12 : 1	9·35	[1] 10·2	10·0	10·2	11·0	..
XVIII.	209	7,500	770	10 : 1	9·4	[1] 10·2	10·0	10·2	10·65	12·05
XIX.	209	7,500	750	10 : 1	9·4	[1] 10·2	10·0	10·2	10·4	11·8
XX.	..	..	..	..	..	[1] 10·2	10·0	10·2	..	..

[1] Derived from guarantees in section A for the same vacuum, viz. 84 per cent.

difference between the guaranteed steam consumptions of the French, German, and Swedish firms, and those found from the test results given in Table XXVIII., which are the values of steam consumption derived from published tests corrected to a constant absolute pressure of 13 kilograms and an 86·6 per cent. vacuum

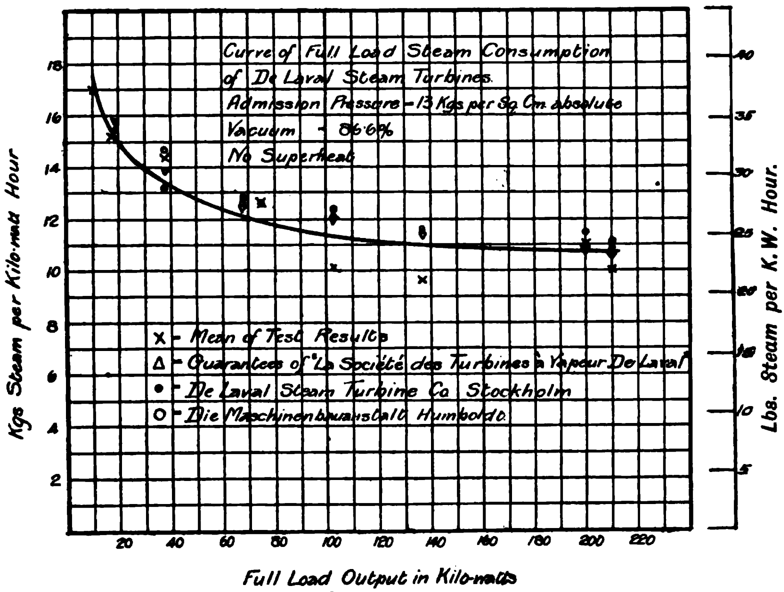


FIG. 24.—Full-Load Steam Consumption.

with no superheat, was extremely small. It has therefore been found advisable to take for these values the mean curve given in Fig. 24. The curve in this figure can now be taken as fairly representing the steam consumption of the de Laval steam turbine at full load, for any rated output from 10 to 209 kilowatts, at an absolute pressure of 13 kilograms and 86·6 per cent. vacuum, with no superheat.

HALF-LOAD STEAM CONSUMPTION.

The steam consumption for designs of various rated outputs has now been found for full load. It is necessary to investigate the matter in the same way for half load. Let us first examine whether the curves in Figs. 20 to 23 can be taken as also corresponding to the conditions at half load. The first step consists in ascertaining whether a curve showing the steam consumption at half load for various pressures has the same law as the corresponding curve for full load.

TABLE XXIX.—ESTIMATED PERCENTAGE DECREASE IN STEAM CONSUMPTION PER DEGREE CENTIGRADE OF SUPERHEAT.

Name of Firm.	Superheat in Degrees Centigrade.	Per Cent. Decrease in Steam Consumption.	Per Cent. Decrease per Degree Centigrade.
Greenwood & Batley, Leeds	10° C.	4·0	0·400
Greenwood & Batley, Leeds	37·7° C.	7·0	0·186
Greenwood & Batley, Leeds	65·5° C.	9·5	0·145
Société De Laval	50° C.	8·0	0·160
Société De Laval	80° C.	10·0	0·125
Humboldt Co.	50° C.	5·75	0·115

For this purpose, let us first examine the results of the tests of a 19·6 kilowatt set when running non-condensing at various pressures as set forth in Table XXV., under reference No. II. We find the following values for the steam consumption at full and half load:—

TABLE XXX.

Admission Pressure in Absolute Metric Atmospheres.	Steam Consumption in Kilograms per Kilowatt-hour.		Ratio of Half-Load to Full-Load Steam Consumption.
	½ Load	Full Load	
3·5	50	42	1·19
4·5	42	36	1·17
6·3	33	29	1·14
8·0	30	27·7	1·08

From the data in the last column we see that the advantage gained by an increase of admission pressure for a 19·6 kilowatt set running non-condensing is, on the average, so far as this particular test shows, somewhat greater at half load than at full load. Let us, however, investigate the case of the 209 kilowatt set, the largest size manufactured. For this purpose we have analysed the various test results contained in Table XXV. for turbines of this size, and have therefrom deduced the curves

A and B of Fig. 25, showing the dependence of the steam consumption on the admission pressure when running condensing. The ratio of the values in curves A and B is constant at 1·14 for all pressures from 10 to 17 absolute metric atmospheres. The law of variation of steam consumption with varying pressure is therefore, for this case, approximately the same at half load as at full load. Now, inasmuch as the percentage variation of steam consumption per per cent. variation of admission pressure is in

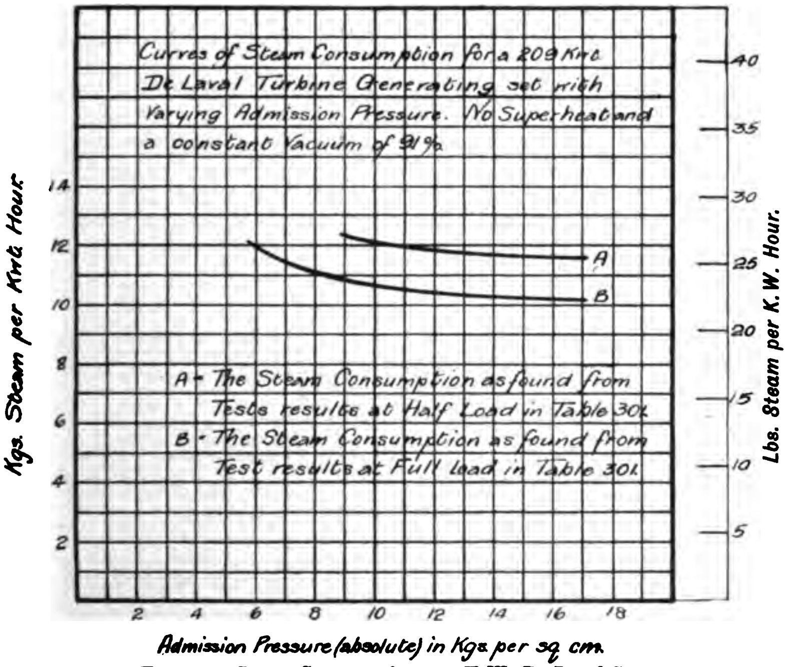


FIG. 25.—Steam Consumption 209 K.W. De Laval Set.

any case such an exceedingly low value, it is evident that no error of consequence will be introduced by using at half load the same correction curves already employed at full load, namely, the curves of Fig. 21, for all sizes of de Laval turbines, in spite of the slight departure from this relation shown by the tests of the 19·6 kilowatt set, when running non-condensing with varying admission pressure. This has been done in the following analysis.

VARYING VACUA AT HALF LOAD.

The next step is to ascertain whether we may also use at half load the curve in Fig. 23 for correcting for varying vacua. For

this purpose it is first necessary to determine the consumption of steam at half load for various sizes, with constant pressure and no superheat, and running non-condensing.

The corresponding values for full load have been plotted from the data in Table XXVI. for an absolute pressure of 13 metric atmospheres, and give us curve A of Fig. 26. The Humboldt Company state that at half load the steam consumption is about 12 per cent. higher than at full load. Even should this percentage not be exactly right, it is sufficiently so to serve the present purpose. Curve B of Fig. 26 is plotted with ordinates 12 per

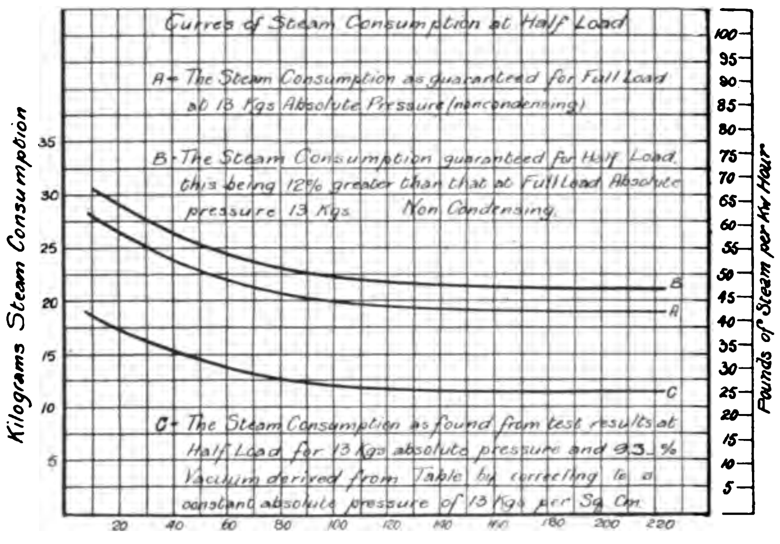


FIG. 26.

(Refer to Tables XXV. and XXVI.)

cent. greater than the ordinates of curve A of Fig. 26, and gives us the approximate steam consumption of the various sizes at half load, 13 absolute metric atmospheres admission pressure, and running non-condensing. Curve C of Fig. 26 has been deduced from an analysis of a number of the test results at half load in Table XXV. By a comparison of curves B and C of Fig. 26 we find that at half load a 93 per cent. vacuum reduces the steam consumption of all sizes to some 56 per cent. of the consumption when working non-condensing. From a comparison of the four curves given in Fig. 22 for full load, we find that the corresponding percentage reduction already ascertained to occur at full load may, for practical purposes, be taken as identical. Hence

we may employ the curves of Figs. 22 and 23 for vacuum corrections, not only at full load, but also at half load.

We thus find that it is practicable to use the data of the set of curves of Figs. 21, 22, and 23, corresponding to full load, for correcting the steam consumption for various pressures and vacua at half load. We can now at once derive the values of the steam consumption at half load for a constant absolute pressure of 13 kilograms and 86·6 per cent. vacuum, and with no superheat. This

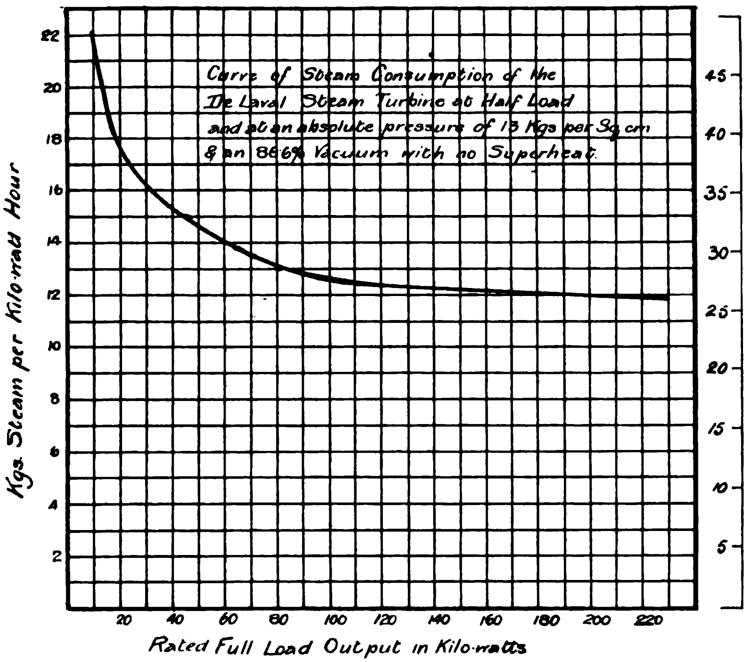


FIG. 27.—Steam Consumption De Laval Turbine at Half Load.
(*Plotted from Values in Column A, Table XXVIII.*)

has been done with the values given in Table XXV., at half load, for various outputs, and the corrected values are shown in the appropriate section of Table XXVIII., and are plotted in Fig. 27. From the curve of this figure we can find the steam consumption at half load for sizes from 10 to 209 kilowatts, at the specified pressure and vacuum.

QUARTER-LOAD STEAM CONSUMPTION.

The same method of investigation has been carried out in the case of the quarter-load values. From the curves of Fig. 28 it

will be seen that for a 19·6 kilowatt set the conditions are approximately the same as at half load, so far as relates to the rate of variation in steam consumption as a function of the admission pressure, the ratio of the values in curve A, representing one-quarter load, to those in curve B, representing full load, ranging from 1·50 at a pressure of 4 absolute metric atmospheres, to 1·38 at 12 metric atmospheres. The rate of increase in steam consumption with varying pressures is taken as remaining fairly constant at full, half, and quarter loads, throughout a wide range of mean pressures. The curves of Fig. 29, which have

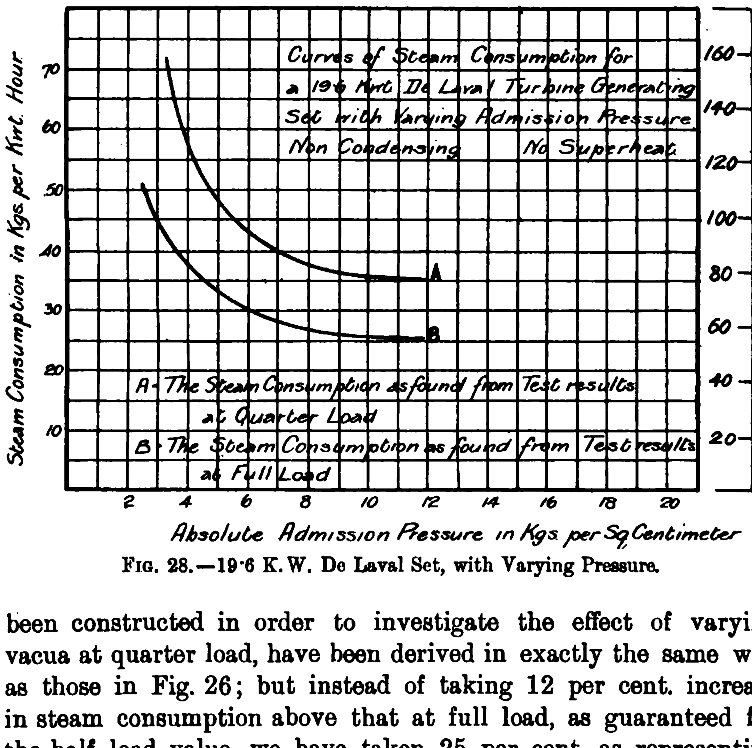


FIG. 28.—19·6 K.W. De Laval Set, with Varying Pressure.

been constructed in order to investigate the effect of varying vacua at quarter load, have been derived in exactly the same way as those in Fig. 26; but instead of taking 12 per cent. increase in steam consumption above that at full load, as guaranteed for the half load value, we have taken 25 per cent. as representing the increase at quarter load, this being the percentage quoted by the Humboldt Company.

The ratio of the values in curves C and B of Fig. 29 is fairly constant for all sizes, and has a mean value of about 0·56. That is to say, a 93 per cent. vacuum decreases the steam consumption at quarter loads to about 56 per cent. of the steam consumption when running non-condensing, the admission pressure being 13

absolute metric atmospheres in both cases. This is about the same percentage decrease already obtained at full load and half load.

From all these results it is evident that we may use the same curves for correcting the quarter load values of steam consumption as have been used for both full and half load values. The steam consumptions taken from Table XXV. for quarter load, after being corrected to a constant absolute pressure of 13 kilograms and an 86·6 per cent. vacuum, with no superheat, are to be found in the appropriate section of Table XXVIII., and the curve

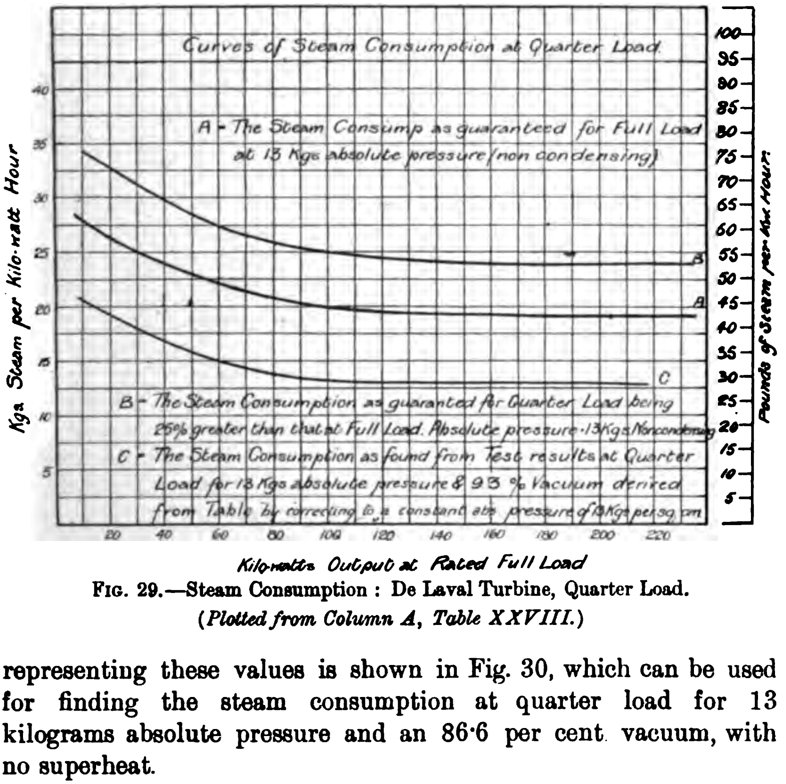


FIG. 29.—Steam Consumption : De Laval Turbine, Quarter Load.
(*Plotted from Column A, Table XXVIII.*)

representing these values is shown in Fig. 30, which can be used for finding the steam consumption at quarter load for 13 kilograms absolute pressure and an 86·6 per cent. vacuum, with no superheat.

Although it is only roughly correct to take the rate of increase in steam consumption with decrease in pressure at half and quarter load, the same as at full load, nevertheless the range of pressures over which we have applied the corrections is, in most instances, not great, and the error thereby introduced in the final average results is certainly too small to be of practical consequence. This also applies to the case of the rate of change

in consumption due to variation in vacuum. Should a de Laval turbine be operated with all the nozzles open at all loads, the effect of increasing pressure would doubtless be to further increase the steam consumption at light loads.

Effect of Superheat on Steam Consumption.

The question of superheat has, up to the present, not been

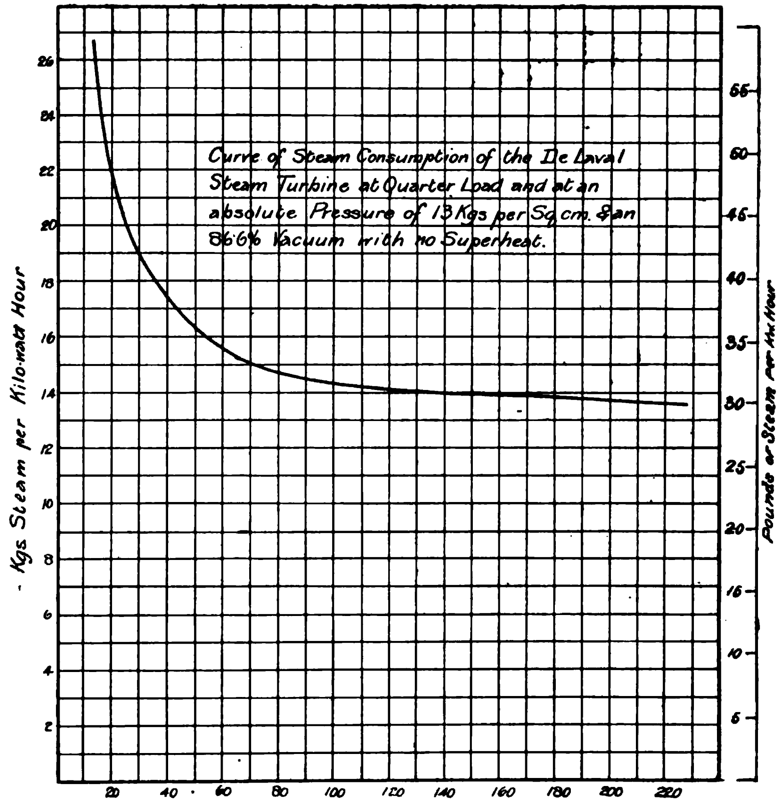


FIG. 30.—Steam Consumption: De Laval Turbine, Quarter Load.
(Plotted from Column A, Table XXVIII.)

touched upon. In order to arrive at representative values for the gain in economy for the de Laval turbine due to a moderate degree of superheat, we have shown in Table XXIX. the percentage gain in economy as estimated by various firms manufacturing this type of turbine, and the means of those values have been employed

in deducing the curve of Fig. 31. From this curve we can estimate the percentage gain in economy per degree Cent. increase in superheat.

The curves of Figs. 24, 27, and 30, which show the steam consumption of the de Laval steam turbine at full, half, and quarter loads, at a constant absolute pressure of 13 kilograms and an 86·6 per cent. vacuum, have been employed as the basis from which we have deduced the steam consumption with a superheat

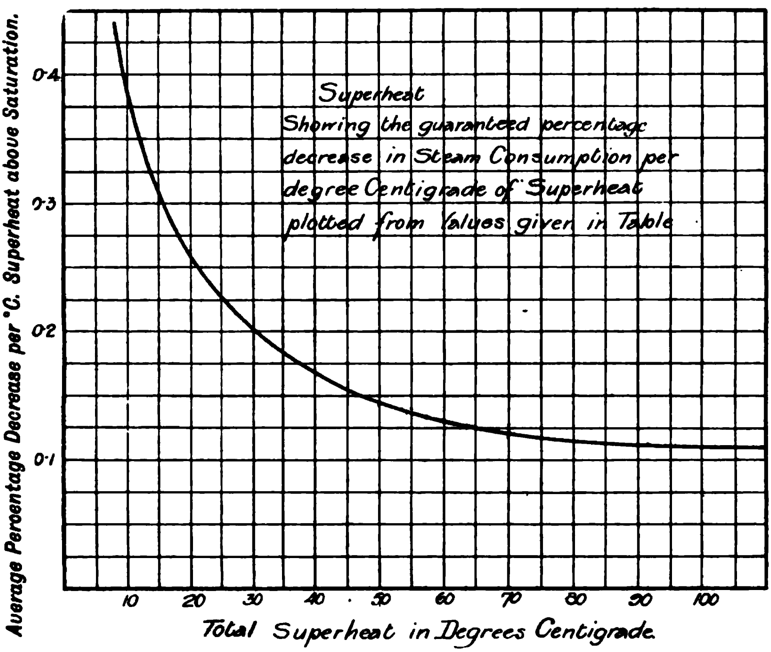


FIG. 31.—Effect on Steam Consumption of Increase in Superheat. (*From Table XXIX.*)

of 50° Cent., and the results are plotted in curves A, B, and C of Fig. 32. As the steam consumption for auxiliaries is only included in one of the tests analysed, the results in Fig. 32 are to be taken as representing the consumption exclusive of auxiliaries.

In Table XXVIII., column B, will be found the steam consumption values taken from Table XXV., and transformed to a constant absolute pressure of 13 kilograms per square centimetre, and an 86·6 per cent. vacuum, with a superheat of 50° Cent., at full, half, and quarter loads.

In Fig. 33 are shown for an absolute pressure of 13 kilograms and 86·6 per cent. vacuum and a superheat of 50° Cent., for the entire range of rated capacities, the percentages by which the steam consumption at half load and quarter load exceed the steam consumption at full load. It is evident from the curves that for all but the smaller sizes, the steam consumption at half load exceeds that at full load by from 10 per cent. to 12 per cent., and

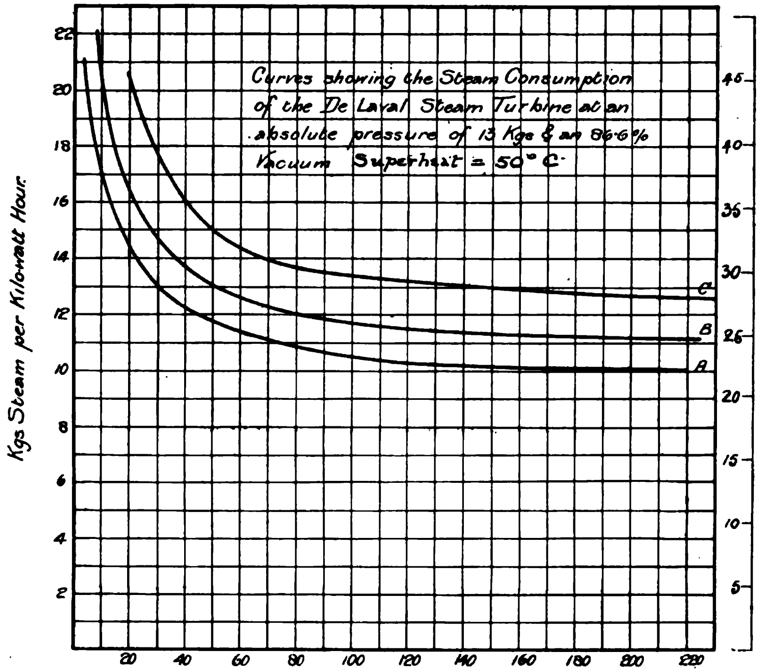


FIG. 32.—Steam Consumption of de Laval Steam Turbine.

A = *Full load from Fig.* 24. *All corrected for Superheat.*
B = *Half load from Fig.* 27.
C = *Quarter load.*

the steam consumption at quarter load exceeds that at full load by some 26 per cent. The percentages only apply when the number of nozzles opened is varied by hand in proportion to the load. In reference No. I. of Table XXV. is given the record of a test on a 19·6 kilowatt generating set by Lea and Meden, in which all the nozzles remained open at all loads. The results, reduced to an admission pressure of 13 atmospheres, a vacuum of 86·6 per cent. and 50° Cent. of superheat, are plotted in Fig. 34, together

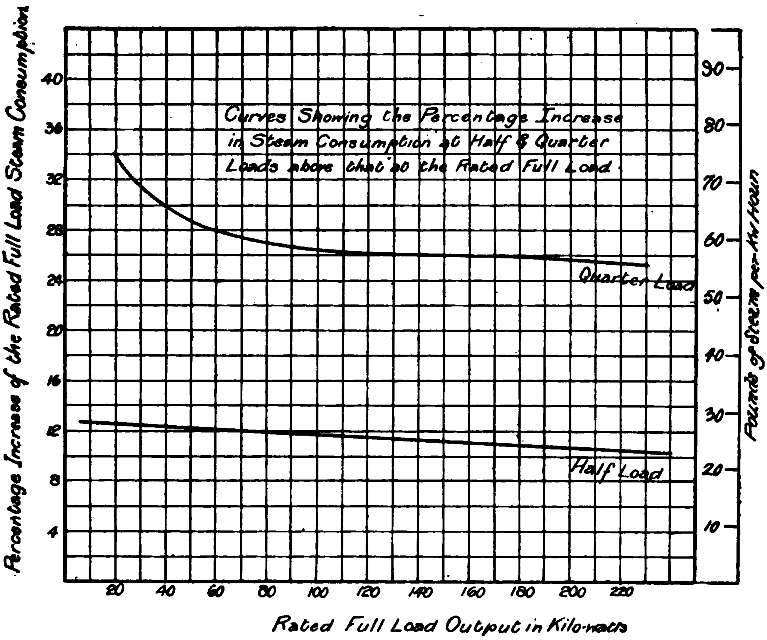


FIG. 33.

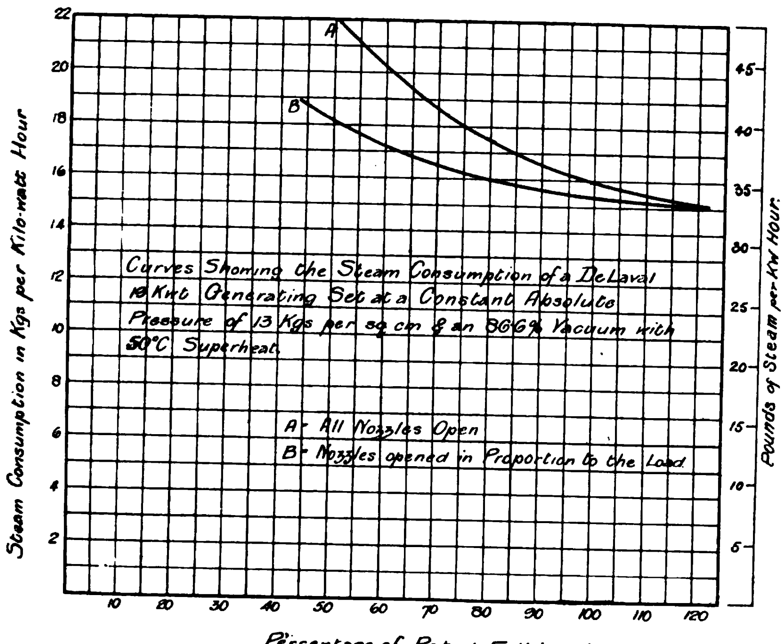


FIG. 34.—Steam Consumption of 19·6 K.W. de Laval Turbine.

with the corresponding results when the number of nozzles opened is changed in proportion to the load. In the case where all the nozzles are open at all loads, it is seen that the steam consumption at half load exceeds the full load steam consumption by 38 per cent. as against only 18 per cent. when the number of nozzles opened is in proportion to the load. Inasmuch as the de Laval turbines are not provided with any automatic arrangements for changing the number of nozzles opened as the load changes, it is not altogether right that the type should have the credit of giving such low results for steam consumption at light loads as are obtained by closing the nozzles as the load decreases.

The Internal Losses in the de Laval Turbine.

A list of these losses has been given on p. 33.

I. Nozzle Losses.—Could the steam be expanded in a diverging nozzle to the desired pressure without any friction or other losses, all the available energy would be transformed into kinetic energy, *i.e.* the steam would flow out with a speed which can be calculated from the following formula:[1]—

Speed in metres per second = 4·44 available energy in kilogrammetres.

There are, however, losses due to the friction of the steam against the inner surface of the nozzle, and most probably also due to the formation of eddies and whirls. It is customary to indicate these losses by stating the corresponding percentage decrease in speed. For correctly designed de Laval nozzles, the speed reduction due to nozzle friction generally varies between 5 per cent. and 8 per cent. The corresponding losses of energy are therefore between 10 and 15 per cent. Delaporte[2] found the exceptionally low value of 2·6 per cent. decrease of speed. Of course the above average losses refer only to correctly designed nozzles. It is clear that a nozzle can be correctly proportioned only for a given amount of steam passing through it and for given conditions as to admission and exhaust pressure. In all cases where a nozzle is used under different conditions from those for which it is designed, the losses will be higher. Any change in the admission pressure or in the exhaust pressure has a great influence on the efficiency of the nozzle, or on the shape of the

[1] This formula is derived from the formula for kinetic energy on p. 28.

[2] Delaporte, *Revue de Mécanique*, 1902, p. 406.

nozzle if properly designed. For instance, it has been shown[1] that if the back pressure is as high as 58 per cent. of the admission pressure of saturated steam, the nozzle ought not to be enlarged conically, but whenever the back pressure is less than 58 per cent. of the admission pressure, the nozzle should be enlarged, and the ratio of the cross section of the nozzle at the end to the cross section at the narrowest point mainly depends upon the ratio of the admission pressure to the exhaust pressure. In Table XXXI.

TABLE XXXI.—DESIGNING DATA FOR DIVERGING NOZZLES.

P_0 = initial pressure.
p = pressure at end of nozzle (*i.e.*, the back pressure).
d = diameter of bore at end.
d_m = minimum diameter.
w = speed at end of nozzle.
w_m = speed at minimum cross section.

$\frac{P_0}{p}$	$\frac{d}{d_m}$	$\frac{w}{w_m}$
1·73	1	1
2	1·01	1·12
4	1·16	1·55
6	1·31	1·74
8	1·44	1·86
10	1·56	1·92
20	1·99	2·18
50	2·83	2·43
60	3·03	2·47
70	3·22	2·51
80	3·40	2·54
90	3·56	2·56
100	3·72	2·58

the relations between these two ratios are given in columns I and II. In column III are given the corresponding values of the ratio of the speed of the steam at the end of the nozzle to the speed at the most contracted point of the nozzle.

From this table Büchner draws some very interesting conclusions which clearly indicate the occurrences when a given nozzle is employed with different pressures.

Let it be assumed that a nozzle is employed of the correct shape for use with saturated steam and an absolute admission pressure of 10 kilograms per square centimetre, the back pressure

[1] Büchner, "Experiments on de Laval Steam Turbine Valves," *Zeitschr. d. V. Deutsch. Ing.*, July 9th, 1904, xlviii. pp. 1029–1036, and July 23rd, 1904, pp. 1097–1103.

being 1 kilogram per square centimetre. From Table XXXI. we find that the diameter at the end of the nozzle should in this case be 56 per cent. larger than at the narrowest point. For this case, let us assume that the pressure at any point of the nozzle has been calculated or found by experiment. If we use the same nozzle for a 20 per cent. greater admission pressure without altering the back pressure, then the pressure at any point of the tube will be 20 per cent. greater than before. As the speed of the steam remains practically constant (one-half of one per cent. increase), the degree of wetness also remains practically constant. The mechanical energy imparted to the steam has therefore remained practically the same (only one per cent. increase), while with another nozzle of suitable design for this greater pressure, the increase in mechanical energy would have amounted to approximately 16 per cent.

Very peculiar phenomena occur when, with a given nozzle, the admission pressure is reduced below the most favourable value. Theoretically, the pressure at each point of the tube should then decrease in the same ratio, *i.e.* the steam should expand to a pressure lower than the back pressure, so that on leaving the nozzle the steam would again be compressed.

There are, however, not yet available the results of sufficiently exhaustive tests to permit of deducing the losses due to such decrease in admission pressure. It is, however, clear that any reduction in the pressure caused by throttling must be accompanied by a loss, in so far as energy capable of being converted into mechanical energy is transformed into heat by losses taking place in the nozzle.

II. Losses due to Leakage between Nozzles and Vanes. —The leakage losses can be taken proportional to the difference of pressure between the end of the nozzle and that at the entrance to the vanes, and to the clearance between the nozzle and the vanes. As in the de Laval turbine the difference of pressure is very small, the leakage losses should also be very small, or possibly even negligible.

III. Losses due to Radiation from the Turbine Casing. —These losses are comparatively small. They are proportional to the difference between the temperature of the turbine casing and that of the surrounding atmosphere and to the surface of the casing. It would, however, be erroneous to conclude that the losses thus occasioned are direct losses, and as such are to be subtracted from the mechanical energy available. This may occur

in some cases, but generally the mechanical energy available is only diminished to the extent of a small part of these losses.

This will be readily understood when we remember that the total of the losses in the turbine itself tends to increase the temperature of the steam. The steam may even leave the turbine with some superheat. If now, during the passage through the turbine, some heat is lost through radiation from the casing, the actual loss in mechanical energy is very small, with the result that the steam, when leaving, simply has a somewhat lower temperature.

IV. Loss due to the Friction of the Turbine Wheel Revolving in the Steam.—This loss is considerable in a non-condensing turbine, but rapidly decreases with increasing vacuum, and, for a given vacuum, decreases with increasing degree of superheat.

At the high peripheral speeds often necessary in the rotors of steam turbines of certain types, the losses due to the resistance of the revolving wheel amount to a considerable percentage of the total input to the turbine. The various factors which exert an influence on this loss can best be discussed in the light of the test results obtained by Lewicki[1] on a 30 horse-power de Laval steam turbine.

An electric motor was used for driving the turbine wheel, which was run in steam of various pressures and degrees of superheat, and in air. In order to separate the bearing and gear losses from the wheel losses, the turbine wheel was removed at one stage of the tests and a determination of the power necessary to drive the shaft and gearing was made. This is given as a function of the speed in curve I of Fig. 35. In curves II and III are given the corresponding values with the wheel revolving in saturated steam at an absolute pressure of 1 kilogram per square centimetre, and in air at the same pressure and at a temperature of 30° Cent. The difference between the last two curves and curve I represents the loss due to the wheel resistance, as it may be assumed with sufficient certainty that the weight of the turbine wheel itself would not alter the bearing losses to any considerable extent. These curves are given in Fig. 36. One sees at a glance that the wheel friction loss does not vary proportionally to the speed, but at a far higher rate. A closer examination shows that it varies

[1] Lewicki, "Die Anwendung hoher Ueberhitzung beim Betrieb von Dampfturbinen," *Zeit. des Vereines Deutscher Ingenieure*, March 28th, 1903 p. 492.

roughly as the 3rd power of the speed. It has been confirmed by several other experimenters that the power lies between 2·8 and 3·5. This loss has a great resemblance to the windage loss in dynamos, and also to train resistance at high speeds. For a very

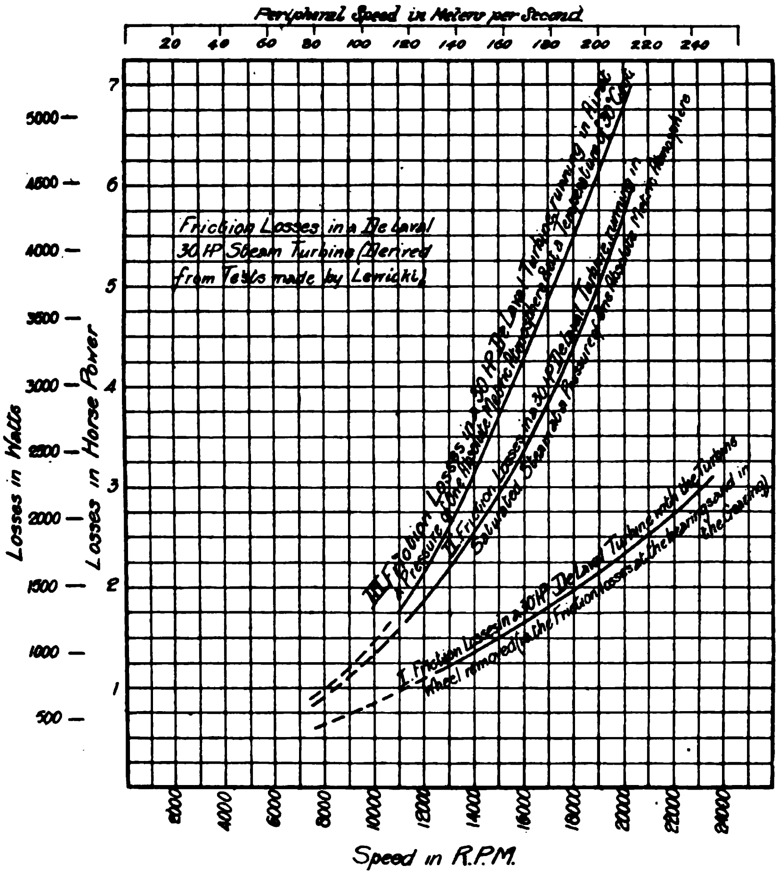


FIG. 35.—Friction Losses in a 30 H.P. de Laval Turbine.

large alternator, one of the authors recently found the windage loss varied approximately as the 3·5th power, but this may have been due to the very excessive vibrations existing at the extremely high speeds at which it was run for the purposes of the test. The train resistance due to wind friction is generally assumed to be proportional to the $\frac{9}{5}$ power, therefore the loss is proportional to the 2·7 power. As an average the 3rd power seems to give a fair agreement with most of the test results.

Judging from Fig. 36, air at 30° Cent., and at absolute pressure of one metric atmosphere, causes a 35 per cent. to 40 per cent. greater loss than saturated steam at the same pressure.

In Fig. 37 the influence of superheat on the wheel losses is shown for an absolute pressure of 1 kilogram per square centi-

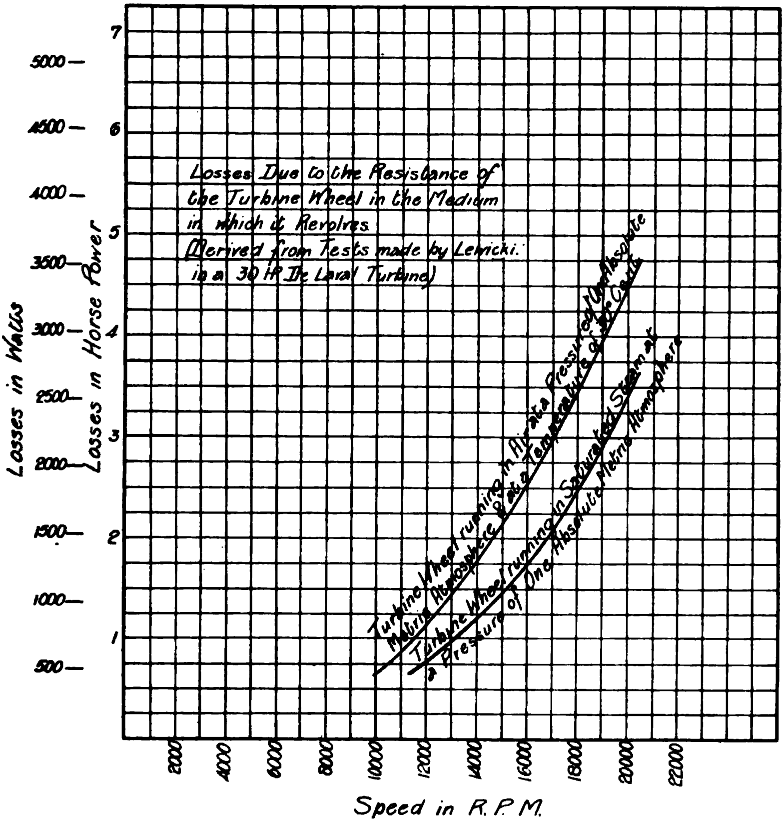


FIG. 36.

metre, and also for an absolute pressure of 0·4 kilogram per square centimetre.

With the exception of a small part of the left-hand end of the curves, the losses seem to decrease proportionately to the increase of superheat. The sudden increase near saturation is most probably due to the presence of water in the steam, and the avoidance of wetness thus forms one of the principal advantages obtained by the employment of superheat. The dotted lines represent the specific weight of the steam, and the close agreement

which exists between the losses and the specific weight seems to indicate that the wheel losses are approximately proportional to the specific weight.

In Fig. 38 the influence of pressure on the friction loss is clearly shown. The range is from 0·4 to 1 kilogram per square centimetre. In this case the values are also approximately proportional to the specific weight.[1] In comparing the losses for different media, this relation no longer holds good. For instance,

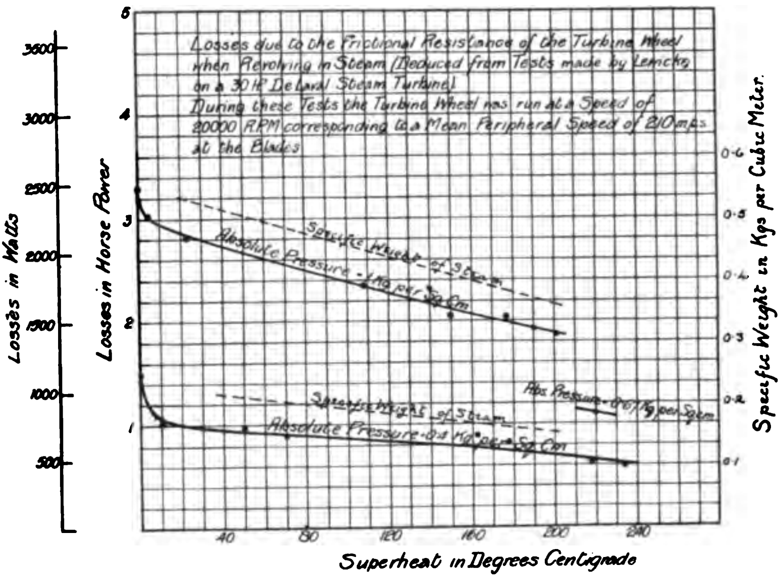


FIG. 37.

in Fig. 36 the losses for air and saturated steam differ roughly in the ratio 1·4 : 1. The specific weight for the same conditions varies, however, in the ratio 1·165 : 0·587 (*i.e.* as 2 : 1), and hence the wheel losses have not increased at nearly so great a rate as the specific weights.

In order to apply these and other results at once to turbines

[1] The weight of one cubic metre of saturated steam is (according to Zeuner, *Tech. Thermodynamik*—Felix, Leipzig, 1901—vol. ii. p. 37) equal to $0{\cdot}588\ p.^{0{\cdot}939}$ Kg., but for any particular case it is more convenient to take it from the steam tables. For superheated steam the volume in cubic metres of 1 kilogram of steam can be found from the expression

$$\text{Volume} = \frac{47{\cdot}1 \times (\text{absolute temperature})}{\text{Abs. pressure in kilogram per sq. metre}} - 0{\cdot}016.$$

This applies to temperatures not far from saturation, according to Tumlirz (see Chap. XIII.).

of different dimensions, Stodola has proposed to take these wheel losses as being proportional to the square of the diameter, the third power of the peripheral speed, and the specific weight of the medium. It seems, however, that the influence of the diameter has been overestimated by Stodola, as this formula gives, for very large diameters, considerably too high values. For instance, Porte[1] remarks that a 150 horse-power de Laval turbine absorbed 35 horse-power at no load when revolving at normal

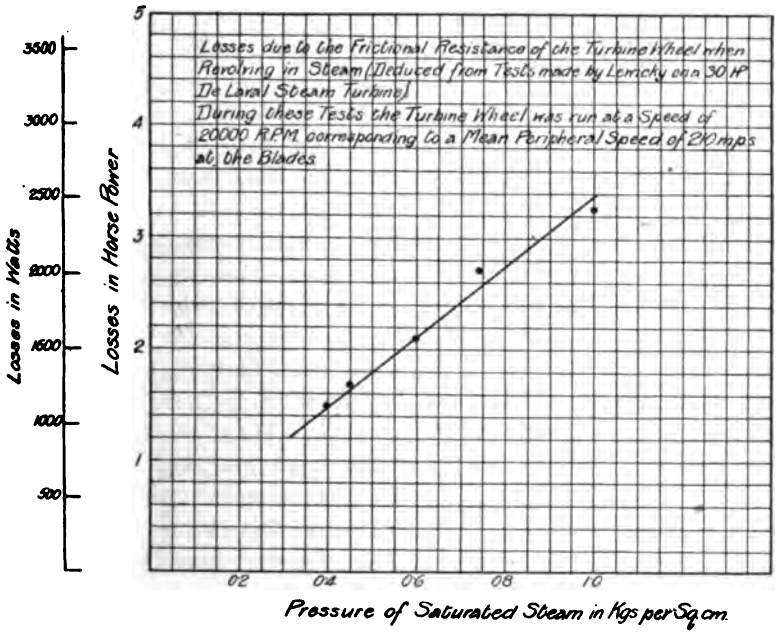


FIG. 38.

speed in steam at atmospheric pressure, and 2·33 horse-power when revolving at the same speed in a vacuum of 28 inches (93·3 per cent. vacuum). The 150 horse-power de Laval turbine has a diameter of 55 centimetres and a peripheral speed of 330 metres per second. The 30 horse-power de Laval turbine tested by Lewicki had a diameter of 20 centimetres and a peripheral speed of 210 metres per second. According to Stodola, the wheel losses of the 150 horse-power turbine would have to be 29 times[2]

[1] Porte, "Steam Turbines," *Journal Inst. Electrical Engineers*, vol. xxxiii. p. 887, February 11th, 1904.

[2] $\left(\frac{55}{20}\right)^2 \times \left(\frac{330}{210}\right)^3 = 29.$

larger than in the 30 horse-power turbine under equivalent conditions. The tests give, however, a ratio of only $35 : 3{\cdot}3 = 10{\cdot}5$. It seems considerably more probable that the wheel losses are proportional to the expression

Diameter$^x \times$ (peripheral speed)$^3 \times$ specific weight of medium, and that the value of x lies between 1·0 and 1·5.

In the 150 horse-power test, the specific weight also had a proportional influence, namely,

$$\frac{\text{Specific weight at 1 atmosphere}}{\text{Specific weight with 28-inch vacuum}} = \frac{0{\cdot}587}{0{\cdot}045} = 13.$$

$$\frac{\text{Losses at atmospheric pressure}}{\text{Losses at vacuum of 28 inches}} = \frac{35}{2{\cdot}33} = 15.$$

Considering the extreme range, these results are in excellent agreement. It must, however, not be thought that the losses measured when the turbine is driven in a stagnant medium are the same as those occurring during actual conditions of operation at full load. The conditions for these two cases offer so many striking differences that it would be a mere coincidence were the losses to be the same in both cases. At full load a part of the vanes are filled by the steam flowing from the nozzles over the vanes and then onward to the condenser. Therefore the conditions would be similar to those in a test with stagnant steam only between two adjacent nozzles. This has also been shown experimentally, as described in Stodola's treatise, 3rd edition, pp. 131, 132. By increasing the number of nozzles, Lasche[1] found considerable decrease in the losses, which can be explained by the decrease in the friction of those vanes filled at any moment with stagnant steam.

A second reason why the wheel losses at full load should be different from the losses observed with stagnant steam lies in the fact that the wheel losses entail a conversion of mechanical energy into heat. At full load a part of the heat is, however, reconverted into mechanical energy, as it has heated the vanes, and these give back the heat to the useful steam. The percentage of the losses recovered stands in a certain ratio to the percentage of total heat convertible into mechanical energy. That is to say, the higher the pressure, the lower the vacuum; and the higher the superheat, the higher will be the percentage of the wheel losses, which may be again converted into mechanical energy. Roughly

[1] Stodola, *Die Dampfturbinen*, 3rd edition, pp. 130 and 131.

speaking, this percentage in practical cases varies between 15 per cent. and 25 per cent.

V. **Losses due to the Friction of the Steam travelling over the Vanes.**—The losses in the steam when travelling over the vanes are entirely different from the losses due to the resistance of the turbine wheel rotating in the steam. The latter losses entail a conversion into heat of mechanical energy of the wheel. The former losses involve a decrease in the speed of the steam, and therefore a conversion of the mechanical energy of the steam into heat. Both losses, however, share in common the feature that the heat they occasion is not entirely lost, but serves to increase the temperature and energy of the steam, and thus allows of partial recovery. These losses are by far the largest of all other components of the total internal loss.

Suppose that the steam at the moment of impact moves along the vanes with a speed of 800 metres per second. Then, theoretically, the steam on leaving the vanes should still have a speed of 800 metres per second. It is, however, found that the speed is, say, only 600 metres per second. A good explanation of all the factors causing this very considerable decrease has not yet been given, but it is generally assumed that the steam within the vanes may set up whirls and eddies, to reduce which the only means seems to be to increase the number of vanes per centimetre of periphery. The loss in energy due to the decrease of the speed from 800 to 600 metres per second can be easily calculated. A kilogram of steam travelling with a speed of 800 metres per second has a kinetic energy of

$$\frac{1}{2 \times 9{\cdot}8} \times 800^2 = 32{,}500 \text{ kilogrammetres,}$$

and at 600 metres per second a kinetic energy of

$$\frac{1}{2 \times 9{\cdot}8} \times 600^2 = 18{,}400 \text{ kilogrammetres.}$$

The total loss is therefore

$$\begin{aligned} 32{,}500 - 18{,}400 &= 14{,}100 \text{ kilogrammetres} \\ &= 33 \text{ kilogram-calories.} \end{aligned}$$

The decrease of the speed generally amounts to from 15 to 25 per cent., though there may be exceptional cases, especially for low speeds, in which the percentage decrease is somewhat smaller.

It must be clearly understood that the speed with which the

steam flows over the vanes is altogether different from the absolute speed of the steam, which, of course, depends upon the peripheral speed of the turbine and upon the curvature of the vanes. The absolute energy taken from the steam should be calculated as before, but by taking the absolute speeds of the steam the difference between these two results would give the energy converted into mechanical energy.

VI. Losses due to Bearing Friction.—Some idea of the magnitude of these losses in a de Laval turbine may be gathered from a consideration of curve III of Fig. 35, which shows the losses in the bearings and gearing of a 30 horse-power motor investigated by Lewicki. These investigations have been described in the preceding section. An examination of the curve indicates that the bearing and gearing loss is some 7·5 per cent. of the rated full-load output.

For a 200 horse-power de Laval turbine, Delaporte[1] assumes about 2·5 horse-power bearing loss.

VII. Loss in Speed-reduction Gearing.—This is very dependent upon the workmanship employed in the manufacture of the gearing. It is, nevertheless, of relatively large amount, and may be taken as at least 5 per cent. in gears in good condition. It doubtless runs well up towards 10 per cent. in moderately worn gears, and hence is a leading cause of any slight increase of steam consumption which probably generally occurs in the course of time in steam turbines. Thus Niethammer[2] refers to a 200 horse-power (140 K.W.) de Laval turbine as having, when new, a steam consumption of 9·7 kilograms per H.P.H., with a vacuum of 71 cms., as against a steam consumption after five years of service of 10·1 kilograms per H.P.H., with a 64 cm. vacuum and (presumably) the same admission pressure and temperature in both cases. These figures, however, reduced to the same vacuum, show a deterioration of only about 2 per cent.

Wear of Vanes or Buckets.—Deterioration is also stated to occur as a consequence of wear of the vanes or "buckets." In this connection the following quotation from Lea and Meden's paper, "The de Laval Steam Turbine,"[3] is not without interest:—

"It might be interesting to touch on the practical difficulties

[1] Delaporte, *Revue de Mécanique*, 1902, s. 406.

[2] *Die Dampfturbinen*, page 104.

[3] Paper by Lea and Meden, entitled "The de Laval Steam Turbine," presented at the Chicago meeting (May and June 1904) of the American Society of Mechanical Engineers, and forming part of vol. xxv. of the *Transactions*.

which the de Laval steam turbine, like any other radically new machine, was compelled to meet, after it had been put on the market. The turbine naturally had its troubles from defects due to faulty workmanship and material, but these have been remedied. There have been troubles with bearings becoming overheated. This was partly due to faulty workmanship, but in many cases it can be ascribed to the lubrication, either to failure in keeping the oil reservoir filled, or else to the sight-feed lubricators, which in themselves might have caused trouble. As more machines have been put on the market, they have become more fully understood, and are therefore receiving better attention; consequently these troubles have been gradually reduced. Furthermore, there has been trouble with the buckets. It has sometimes happened that one or more of the buckets have broken and come out of the turbine wheel, but without doing any further damage. Generally, the turbine, after losing a bucket, can be continued in operation, as the turbine shaft is sufficiently flexible to take care of the unbalancing, though it is best to take out the turbine wheel and replace the buckets. The only explanation of these troubles is that the buckets are subjected to vibratory strains of more or less unknown origin, as their ability to withstand centrifugal force and the action of the steam jet is amply sufficient. In the smaller sizes, below 100 horse-power, broken buckets have been very rare. In the larger sizes it has been somewhat more frequent. Although the causes of bucket breakage are not yet accurately determined, it has been possible to remedy the trouble where it has occurred. One cause of the undue vibrations of the buckets may have its source in the turbine wheel itself, which, if not homogeneous, will, under action of the centrifugal force, expand unevenly in different directions, thereby unbalancing and causing vibration of the wheel at full speed. This trouble has been overcome by replacing the wheel. The buckets are also subject to more or less wear, due to the action of the steam. The cause of this is also very difficult to determine. It may be that the buckets are chemically affected and that thin films of oxide are blown away by the steam, or it may be caused by mechanical wear due to small solid particles coming with the steam, such as rust or scale from the pipes. It may also be due to some electrical phenomena. However this may be, it is a fact that wear takes place, and it is very doubtful that it can be entirely prevented. It has been found in a few cases that buckets have been worn out in a year, necessitating replacement. In other cases the wear has been very slight, even after a run of four or

five years. The wear affects only the steam inlet side of the buckets, and will only increase the steam consumption to a slight degree. In tests made on a turbine of 100 horse-power, where the edge of the buckets had been worn away about one-sixteenth of an inch, the steam consumption was about 5 per cent. higher than with new buckets. The wheel and buckets are, however, so designed that an insertion of a new set of buckets can be easily made at a small cost."

Curve III of Fig. 35 shows the value of the loss in bearings and gearing for a 30 horse-power de Laval turbine. Delaporte[1] estimates the gearing losses of a 200 horse-power de Laval turbine at as low as 1 per cent., whilst the gearing and bearing friction combined of a 300 horse-power de Laval turbine in good condition should, in his opinion, be roughly taken as 3 per cent.

VIII. Losses in Dynamo.—These may be obtained from the efficiency curves already given in Figs. 16 to 19, from which it is seen that at full load they range about 7 per cent. of the output in the largest size (209 K.W. dynamo coupled to 300 horse-power turbine), up to some 15 per cent. in a 10 K.W. size. At one-quarter load the dynamo losses range from some 18 per cent. of the output in a 209 K.W. size, down to some 30 per cent. in a 10 K.W. size. It is important that the extent of these losses at light loads in small sizes should be realised, for in the case of an electric generating set in which the load fluctuates so widely that the average load is but a small percentage of the rated load, a higher "all-day" economy would be obtained by a dynamo especially designed to have high efficiency at light loads, even at the sacrifice of a few per cent. in the full-load efficiency.

IX. Losses due to Residual Kinetic Energy in the Steam passing to the Condenser.—The steam passes to the condenser still possessed of a considerable percentage of the energy with which it entered the admission nozzle. It may be roughly stated that this rejected energy will be less the nearer the velocity of the turbine blades approaches one-half the velocity of the impinging steam. In the 300 horse-power turbine the mean diameter at the blades is 0·76 metre, and the speed of the wheel is 10,600 r.p.m. The linear velocity of the blades is thus 424 metres per second. With an admission pressure of 13 absolute metric atmospheres and a condenser pressure of 86·6 per cent., the absolute velocity of the impinging steam, allowing 15 per cent. loss in the nozzle, will be 1090 metres per second. At the usual

[1] Delaporte, *Revue de Mécanique*, 1902, s. 406.

angles at which the nozzles are inclined to the direction of movement of the vanes, this velocity may be imagined to be resolved into two components: one in the direction of the movement of the blades, and amounting to about $0{\cdot}94 \times 1090 = 1030$ metres per second, and the other component perpendicular to the first one, and amounting to $0{\cdot}34$[1] $\times 1090 = 370$ metres per second. We may assume (see p. 77) that the speed of the steam relative to the vanes decreases 20 per cent. during the passage over the vanes. Hence the speed of 370 metres per second is reduced to 296 metres per second. The other component would be reduced by an amount equal to twice the peripheral speed of the vanes, provided that no vane friction existed. Allowing, however, for the assumed 20 per cent. less in the relative speed, the resulting decrease in speed is equal to some 2·25 times the peripheral speed.

$$1030 - 2{\cdot}25 \times 424 = 1030 - 954 = 76 \text{ metres per second.}$$

The absolute speed of the steam after leaving the vanes is equal to

$$\sqrt{76^2 + 296^2} = 306 \text{ metres per second.}$$

The energy loss in percentage of the energy of the steam on emerging from the admission nozzles is equal to

$$\left(\frac{306}{1090}\right)^2 \times 100 = 7{\cdot}8 \text{ per cent.}$$

In the smaller sizes the blade velocity is still lower, and the energy passing on to the condenser is a correspondingly greater percentage of the total energy in the steam at admission.

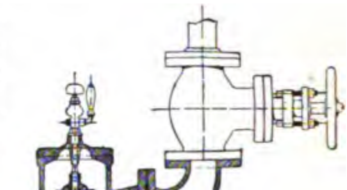
Summation of Losses.—In view of these analyses of the component losses, we are in a position to make a rough allocation of the total loss amongst these components.

Taking the case of a 209 kilowatt set and denoting by 100 the gross energy supplied to the admission nozzles, the distribution is roughly as follows :—

1. Nozzle losses	12
2. Leakage losses 3. Radiation losses	} 1
4. Losses due to friction of the turbine wheel revolving in the steam	4
5. Losses due to friction of the steam travelling over the vanes	9
6. Losses due to bearing friction of wheel	1
7. Losses in speed reduction gearing	2
8. Losses in dynamo	4
9. Losses due to residual kinetic energy in the steam passing to condenser	8
Output	59
Gross input	100

[1] $0{\cdot}94 = \cos 20°$; $0{\cdot}34 = \sin 20°$.

Of course, the conditions under which the turbine runs, *i.e.* whether with or without condenser, whether at the most favourable speed or at a speed far below the most favourable speed, would change the relative importance of the component losses, but the above may be considered to give a rough idea of the amount and distribution of these losses in a normal de Laval turbine of the 300 horse-power (209 kilowatt) size when running condensing.



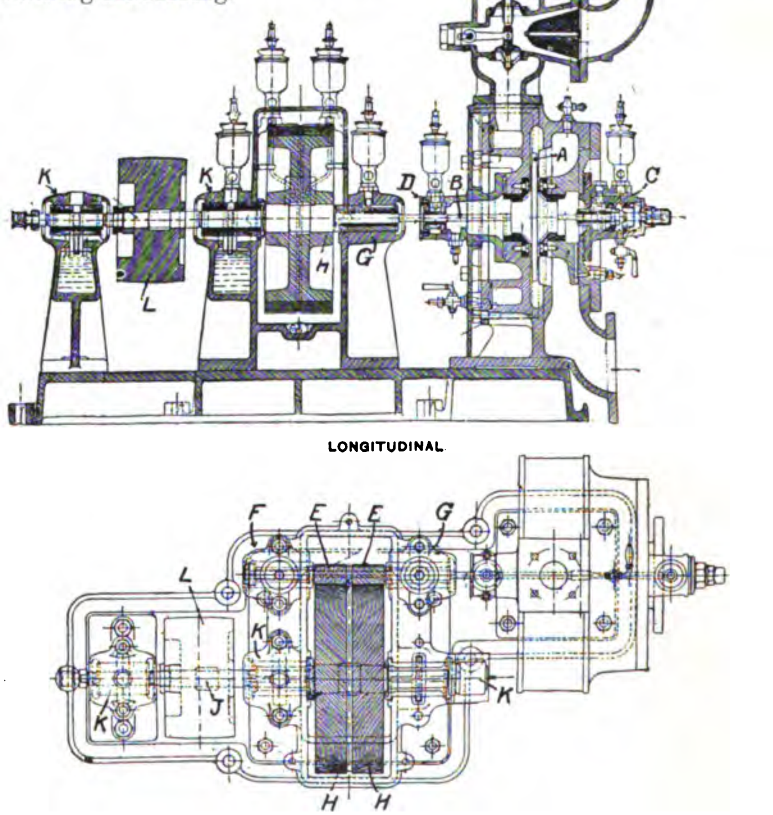


FIG. 39.—20 H.P. de Laval Turbine.

General Description.—In Fig. 39 are shown drawings of a 20 horse-power de Laval turbine.

The turbine wheel A is mounted upon the flexible shaft B between the spherical-seated bearing C and the stuffing box D. The teeth of the two pinions EE are cut in the metal of the shaft

itself. Bearings FG supported in the frame of the gear case are provided just outside the pinions. The pinions EE engage the gear wheel H mounted on the shaft J, supported in the bearings KKK. The power is in this instance transmitted from the pulley L.

A case in which a dynamo is driven from the power shaft is shown in the sectional plan in Fig 40,[1] which represents a 30 horse-power continuous-current set. The rated capacity of the dynamo is 20 kilowatt. Excellent outline drawings with numerous dimensions are given for a de Laval 200 horse-power set on p. 227 of the third edition of Stodola's treatise *Die Dampfturbinen.* In sets of from 50 horse-power upwards, two gear wheels, two power shafts, and two dynamos are employed. The arrangement of the two power shafts is well illustrated in Fig. 41, taken from an article in *Machinery* for November 1904, entitled "The de Laval Steam Turbine and its Manufacture." The illustration, which is a horizontal sectional view taken through the turbine and gear shafts, shows strikingly the relative sizes of the turbine and the reduction gearing.

The Turbine Wheel.—In the small and medium sizes the design of wheel shown in Fig. 42 is employed. T, the hub of the wheel, is bored out, and a thin steel bushing is drawn into the hub by a nut at one end. The middle portion of the bushing is bored with a taper of 4 per cent. The bushing is forced on the shaft and then pinned in place as shown.

The wheel may be removed from the shaft by drawing it off the steel bushing after removing the nut.

Since the presence of a hole, no matter how small, through the turbine wheel reduces its strength to at least one-half, it has been found necessary, in the larger sizes of de Laval turbines, where very high peripheral speeds are employed, to abandon the design shown in Fig. 42 in favour of that shown in Fig. 43, in which a solid hub is recessed at each end, and the flexible shaft is made with enlarged flanged ends which fit into the recesses and are bolted solidly in place. The recesses and shaft ends are machined with a 4 per cent. taper in order that the parts may be accurately centred and fitted solidly together.

The turbine wheels are made of a special grade of high carbon steel. Musil (*Bau der Dampfturbinen*, p. 66, Leipzig, B. G. Teubner) states:—

"The turbine wheel is made from the toughest homogeneous

[1] Taken from an article by Charles Garrison, entitled "The de Laval Steam Turbine," *Technology Quarterly* for March 1904,—Massachusetts Inst. of Technology.

nickel steel, with a breaking strength of about 90 kilogram per

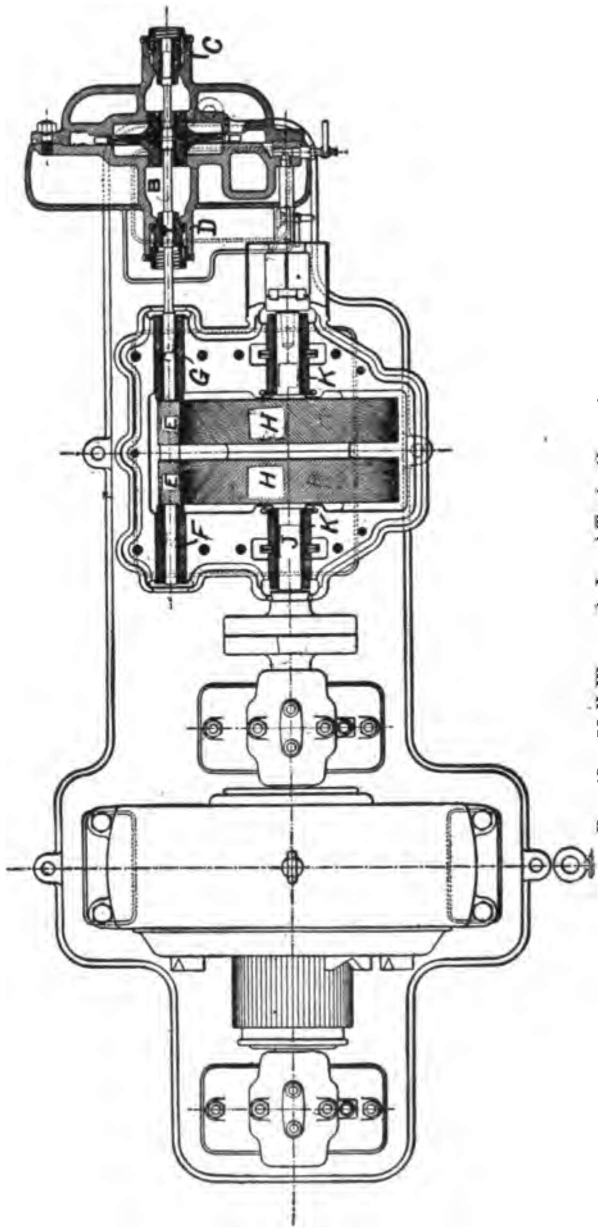


FIG. 40.—20 K.W. c.c. de Laval Turbo-Generator.

square millimetre, 10 to 12 per cent. elongation, and with an elastic limit of 65 kilogram per square millimetre."

This doubtless relates to the de Laval turbines manufactured by the Humboldt Company. The form of the wheel, with the section increasing toward the hub, is arrived at by proportioning

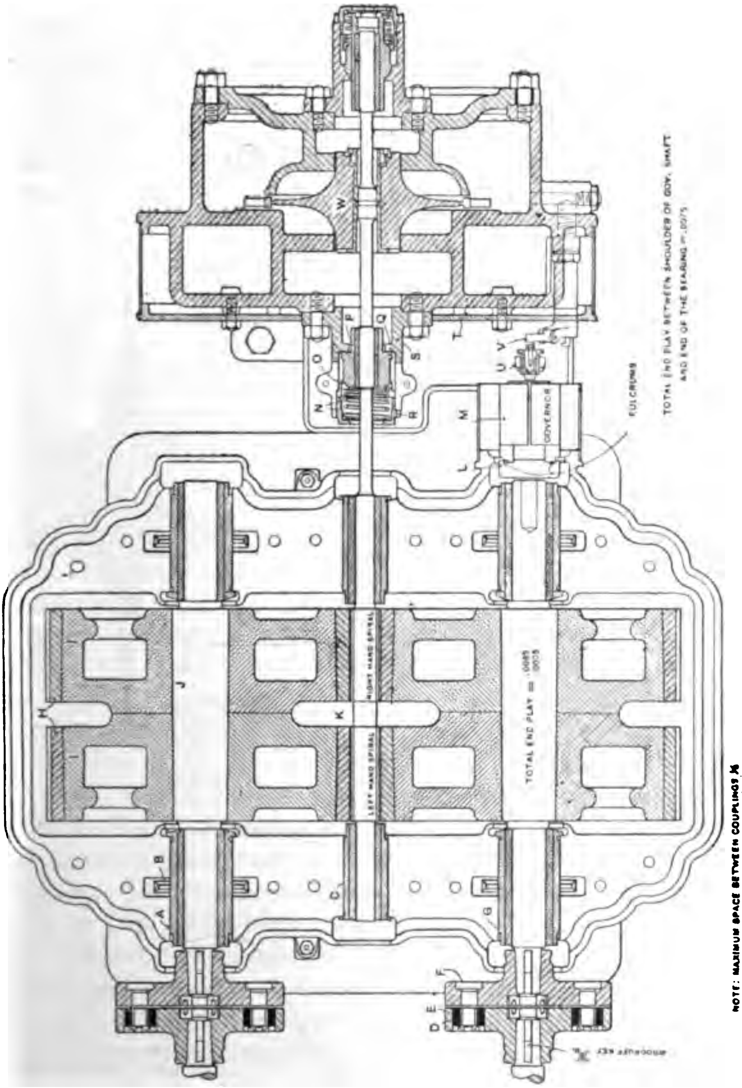


FIG. 41.—Horizontal Section through de Laval Steam Turbine.

it to have equal specific stresses throughout, and a factor of safety of about 8. This does not hold true at the rim, where, just below the blades, annular grooves are turned on each side of the wheel, with the object of ensuring that in the case of a dangerously high

speed being accidentally attained, due to failure of the governor, the wheel shall burst at this point, as the section is so reduced that the specific stresses are about 50 per cent. higher than in the rest of the wheel. At normal speed the factor of safety at this reduced section is about 5; and since the stresses vary with the square of the speed, the wheel will burst at this point at about double its normal speed. It has been found by actual experiments that no great damage results, for the rim holding the buckets is broken up into very small pieces, which can do no damage to the wheel case. Lea and Meden[1] state that in tests on wheels not having this reduced section at the rim, the wheels have burst through the centre in two or three heavy pieces, and the pieces have been driven through an experimental wheel case of steel castings having walls two inches thick. With the wheels as made, however, they are perfectly safe; and in the event of the rim being stripped, no damage will result except to the wheel itself. Furthermore, as soon as the rim breaks, the wheel becomes unbalanced; and as the clearance between the heavy hub of the wheel and the safety bearings in the surrounding wheel casing is very small, as may be seen from Fig. 39, the hub of wheel will, owing to the flexibility of the shaft, come in contact with the sides of these circular openings in the casing into which it extends, and these will act as a brake on the wheel and assist in bringing it to rest. With the buckets broken off, the steam can no longer act to rotate the wheel,

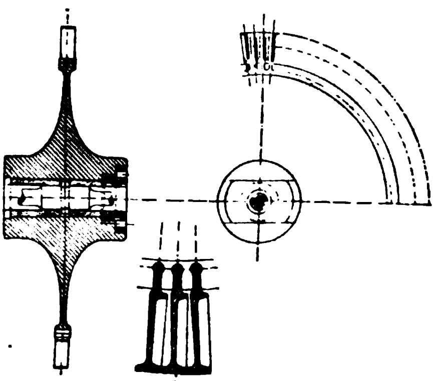


FIG. 42.

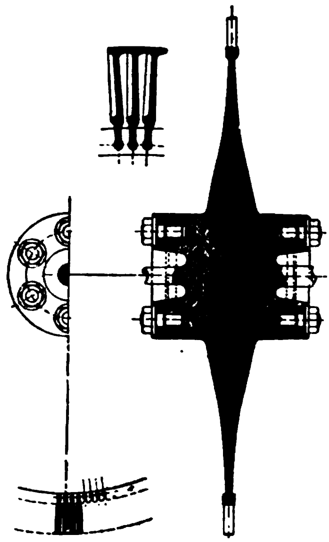


FIG. 43.

[1] "The de Laval Steam Turbine" (*Amer. Soc. Mech. Engrs.*, vol. 25, p. 1056, June 1904).

and it is merely a case of dissipating the energy already stored up in the wheel in virtue of its motion.

Blades or "Buckets":—At the periphery of the wheel are mounted the blades, or, as they are sometimes termed, "buckets." These are well illustrated in Fig. 44, which relates to the blades and wheel of a 20 horse-power turbine, as built by the de Laval Steam Turbine Company of America.

The blades carry extensions at the upper end which fit against one another, thus presenting a continuous ring as the outermost periphery of the wheel over the blades.

As shown in Fig. 44, grooves are drilled and milled in the rim of the turbine wheel in a crosswise direction. The buckets, which are of drop forged steel, are fitted into these grooves, and lightly caulked when in place. Hence the buckets can be readily removed and renewed. The question of deterioration of the buckets has already been discussed on pp. 78, 79, and some particulars of the wheels and buckets for the different sizes are given in Table XXXII.

Construction of the Nozzles.—The only parts of the turbine that have to be changed to make the machine suitable for any particular admission pressure, and degree of superheat and of vacuum, are the nozzles. Their number, size, and form are chosen with reference to the above three conditions. The ratio of the condenser pressure to the boiler pressure determines in a general way the ratio of the areas of cross section of the diverging nozzle at the inlet and at the outlet; for, in order to obtain the maximum of economy, the expansion must be complete just before the steam emerges from the mouth of the nozzle. The actual size of these cross sections and the number of nozzles are determined from the total steam consumption necessary for the required output. The precise shape and length of the nozzle is determined from experience. It is necessary that a certain distance should intervene between the cross section at admission and the cross section at the mouth of the nozzle, otherwise the expansion could not be efficiently and satisfactorily completed, but any undue length would only result in increased loss, due to the friction of the steam against the sides of the nozzle. As the steam consumption at light loads is nearly proportionally smaller than at full load, the nozzles will only be efficient when the number opened is varied as the load varies. The loss in economy when this adjustment is not made has already been shown by the two steam consumption curves in Fig. 34. It has been proposed to have the opening and closing of the nozzles effected automatically by a governor acting with

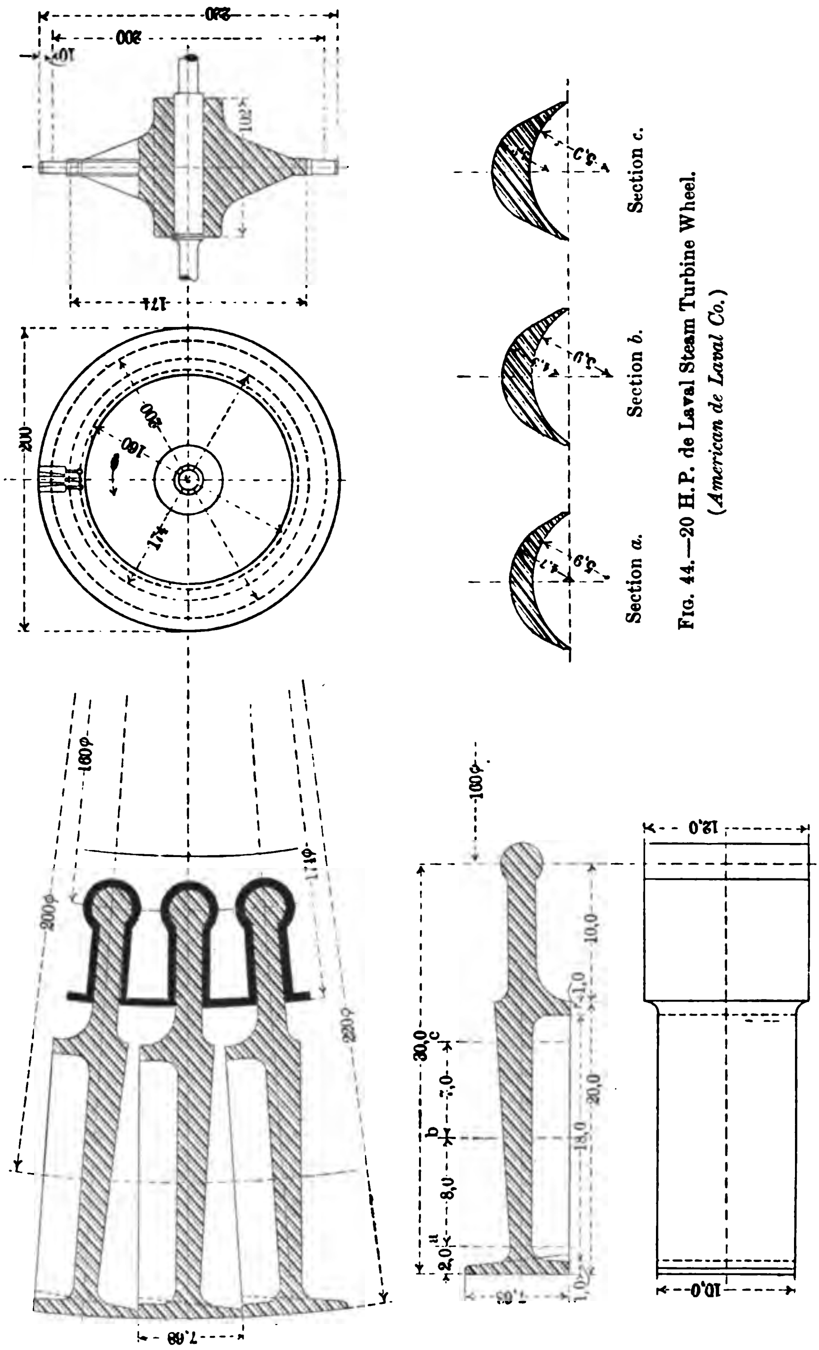


FIG. 44.—20 H.P. de Laval Steam Turbine Wheel.
(*American de Laval Co.*)

TABLE XXXII.—SOME DATA OF WHEELS AND VANES OF VARIOUS SIZES OF DE LAVAL STEAM TURBINES.

Rated Output in H.P.	Rated Output in K.W.	Country in which Turbine is Manufactured. S=Sweden, E=England, F=France, G=Germany, A=America.	Rated Speed of Turbine Wheel in R.p.m.	Diameter of Wheel to Middle of Length of Vane in Millimetres.	Peripheral Speed in Metres per Sec.	Effective Length of Vanes in Millimetres (rough estimate).	Width of Vanes.	Centrifugal Force on Vanes in Metric Tons per Kilogram Weight of Vane.	Weight of Vane in Kilograms.	Total Centrifugal Force per Vane in Metric Tons.	Total Centrifugal Force for all Vanes in Metric Tons.	No. of Vanes—generally rough data.	Pitch of Vanes in Millimetres at Mean Circumference (from rough data).
1·5	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	E	40,000	..		..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	1·0	A	39,000	75 about	..	..	..	64	..	..	..	..	..
3	..	..	..	..	..	..	..	..	..	..	..	..	..
	1·6	E	30,000	100	157	..	..	28	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	G	30,000	100	157	5	..	28	..	..	..	..	..
	2	A	..	..	..	..	..	..	..	..	..	..	..
5	..	..	..	..	..	..	..	..	..	..	..	..	..
	3·2	E	30,000	100	157	16	9	28	..	..	..	44	7·2
	3·0	F	..	...	..	..	..	..	..	..	..	..	..
	..	G	30,000	100	157	5	..	28	..	..	..	..	..
	3·3	A	..	..	..	..	..	..	..	..	..	..	..
7	..	..	..	..	..	..	..	..	..	..	..	..	..
	4·4	E	30,000	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	4·6	A	..	..	..	..	..	..	..	..	..	..	..
10	..	..	..	..	..	..	..	..	..	..	..	..	..
	6·6	E	24,000	..	..	..	..	..	..	..	..	..	..
	6·1	F	24,000	110	138	..	..	..	..	..	..	..	..
	..	G	24,000	150	167	8 or 12	..	48	..	..	..	..	..
	6·6	A	24,000	..	..	..	..	..	..	..	..	..	..
15	..	..	..	..	..	..	..	..	..	..	..	..	..
	9·9	E	24,000	150	188	..	..	48	..	..	..	..	..
	9·4	F	..	..	..	..	..	..	..	..	..	..	..
	..	G	24,000	150	167	8	..	48	..	..	..	110	4·3
	10·0	A	..	..	..	..	..	..	..	..	..	110	4·3

TABLE XXXII.—*continued.*

Rated Output in H.P.	Rated Output in K.W.	Country in which Turbine is Manufactured. S = Sweden | F = France | A = America. E = England | G = Germany	Rated Speed of Turbine Wheel in R.p.m.	Diam. of Wheel to Middle of Length of Vane in Millimetres.	Peripheral Speed in Metres per Sec.	Effective Length of Vanes in Millimetres (rough estimate).	Width of Vanes.	Centrifugal Force on Vanes in Metric Tons per Kilogram Weight of Vane.	Weight of Vane in Kilograms.	Total Centrifugal Force per Vane in Metric Tons.	Total Centrifugal Force for all Vanes in Metric Tons.	No. of Vanes—generally rough data.	Pitch of Vanes in Millimetres at Mean Circumference (from rough data).
	..	..	..	..	..	..		..	..	..	..	..	..
	13·2	E	20,000	..	..	..	..	..	..	..	..	..	..
20	12·6	F	..	..	..	..	..	..	..	..	..	..	..
	..	G	20,000	200	210	10	..	45	..	.	..	..	..
	13·2	A	..	..	..	18	10	..	..	..	..	88	7·2
	..	..	..	..	..	..	..	..	..	..	..	..	..
	20·0	E	20,000	225	236	..	..	..	..	..	..	..	..
30	19·1	F	..	..	..	..	..	..	..	..	..	..	..
	..	G	20,000	200	210	10	..	45	..	..	..	..	..
	20·0	A	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	33	E	16,400	300	256	..	..	..	..	..	..	..	..
50	32·3	F	..	..	..	..	..	..	..	..	..	..	..
	..	G	15,000	300	235	15	..	37	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	E	16,400	..	..	..	..	..	..	..	..		..
55	..		...	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	35	A	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	50	E	16,500	..	..	..	..	..		..	..	..	..
75	48	F	..	..	..	..	..	..	..	.	..	..	..
	..	G	15,000	300	235	15	..	37	..	..	.	..	..
	50	A	16,500	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	E	13,000	500	340	.	..	..		..	..	..	..
100	..	F	15,000	300	..	..	..	..	..	..	..	..	..
	..	G	12,600	500	330	25	10	44	..		..	202	7·8
	..	..	..	..	..	.	..	..	..	..	..	..	..

TABLE XXXII.—*continued.*

Rated Output in H.P.	Rated Output in K.W.	Country in which Turbine is Manufactured. S=Sweden | F=France | A=America. E=England | G=Germany	Rated Speed of Turbine Wheel in R.p.m.	Diam. of Wheel to Middle of Length of Vane in Millimetres.	Peripheral Speed in Metres per Sec.	Effective Length of Vanes in Millimetres (rough estimate).	Width of Vanes.	Centrifugal Force on Vanes in Metric Tons per Kilogram Weight of Vane.	Weight of Vane in Kilograms.	Total Centrifugal Force per Vane in Metric Tons.	Total Centrifugal Force for all Vanes in Metric Tons.	No. of Vanes—generally rough data.	Pitch of Vanes in Millimetres at Mean Circumference (from rough data).
110	..	..	..		..	..	..	..	..	..	..	..	..
	75	E	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	75	A	13,000	..	..	..	..		..	..	..	..	..
150	..	..	..	..		..	..	..	..	..	..	..	..
	100	E	13,000	500	340	..	..	..	..	..	..	..	..
	97	F	..	..	..	..	..	..	..	..	..	..	..
	..	G	12,600	500	330	25	..	44	..	..	..	..	..
	100	A	12,000	..	..	..	..	..	.	..	..	..	..
200	..	S	..	.	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	F	9,000	500	..	..		..	.	..	..	..	..
	..	G	..	500	..	25	10	.	..	..	..	192	8·2
	..	..	..	.	..	..	..	..	...	..	..	..	..
225	..	..	..	..	..	..	..	..	..	..	..	..	..
	150	E	11,000	..	..	..	..	..	..	..	..	..	..
	148	F	..	..	..	..	..	..	..	..	..	..	..
	..	G	12,000	620	390	30	..	50	..	..	..	..	..
	150	A	..	..	..	.	..	..	..	..	..	..	..
300	..	S	..	..	..	..	..	..	..	..	..	..	..
	200	E	10,600	760	425	35	..	..	..	..	..	..	..
	..	F	7,500	700	..	..	.	..	.	..	..	..	..
	..	G	10.500	760	420	35	12	47	0·016	0·75	150	196	12·2
	200	A	10,500	..	..	..	..	..	..	..	..	196	12·2
350	..	.	..	..	..	..	..	..	..	..	..	..	..
	..	.	..		..	..	..	..	..	..	..	..	..
	232	F	..	..	..	..	..	..	..	.	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..	..	..

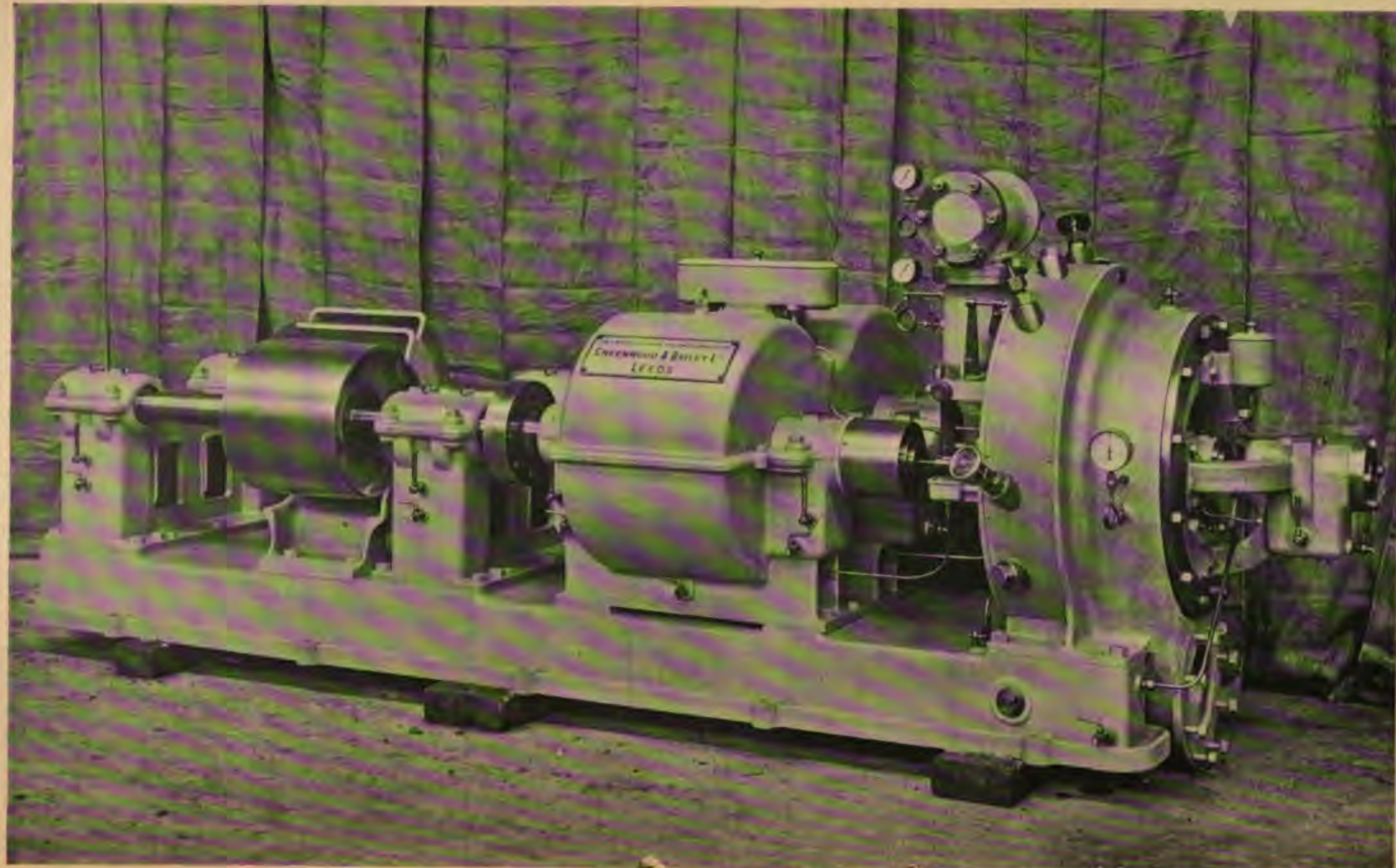


FIG. 45. —225 H.P. Turbine.
(*Showing some nozzle holes plugged. Photo supplied by Messrs Greenwood & Batley, Ld.*)

variations in load. But in practice de Laval turbines are regulated by hand so far as relates to control of the nozzles, and hence it is probable that they are often operating at light loads with all the nozzles open, and hence at lower efficiency.

De Laval turbines, as supplied by Messrs Greenwood & Batley, Leeds, are provided with such a number of nozzle holes as to always make it possible to put in the required number of nozzles for any admission pressure between 5 and 15 absolute metric atmospheres. In Fig. 45, which is a photograph of a 225 horse-power turbine motor, two of the additional nozzle holes plugged up instead of fitted with adjustable nozzles are seen.

The degree of superheat affects the design of the nozzles so slightly as not to render it necessary to employ special designs. Lewicki[1] has, however, found that for very high degrees of superheat the

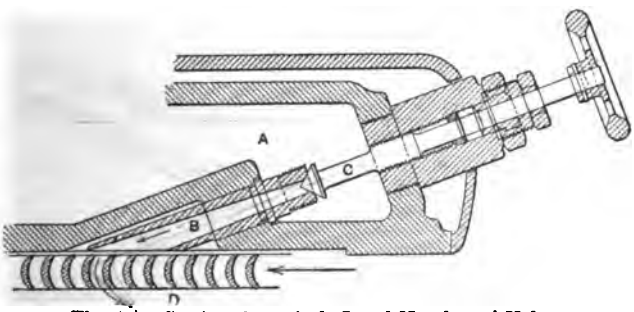


Fig. 46.—Section through de Laval Nozzle and Valve.

bronze nozzles and valves of a 30 horse-power turbine with which he experimented had to be replaced by others of iron, on account of the lower coefficient of expansion of the latter material.

It thus appears that a de Laval turbine provided with nozzles for a certain pressure and vacuum will not give the best results with different boiler and condenser pressures, and the nozzles should be changed to suit the changed conditions. Sometimes turbines are fitted with two sets of nozzles, the one set suitable for running condensing and the other for running non-condensing.

Fig. 46 shows a section through a nozzle and valve as built at the de Laval Steam Turbine Works at Trenton, N.J. In this figure the valve C operated by the hand wheel opens or closes the passage for the steam from the steam chest A to the nozzle B. On emerging from the mouth of the nozzle B, the steam impinges

[1] "Die Anwendung hoher Ueberhitzung beim Betrieb von Dampfturbinen," Ernst Lewicki, *Zeitschr. Vereines Deutsch. Ing.*, 47, pp. 441–447, March 28th, 1903, pp. 491–497, April 4th, 1903, pp. 525–530, April 11th, 1903.

upon the blades D of the turbine wheel, delivering up to the wheel the bulk of its kinetic energy, and passing off at the other side of the wheel to ultimately arrive at the condenser. In an article in *Machinery* (p. 124, Nov. 1904), it is stated that "the nozzles are turned to gauge on their outside and reamed to the required taper on the inside. Over 600 reamers of different tapers are kept in the tool room of the works at Trenton, N.J., U.S.A., for this purpose. The nozzles are simply driven into place in the casing, but are threaded at their inner ends to facilitate removal by means of a jamb nut. The taper of the nozzles ranges from about 6 to 12 degrees total taper, and they are located with their outlet about 3 millimetres from the wheel blades."

Messrs Greenwood & Batley's design of nozzle and valve and stuffing box is indicated in the sketch in Fig. 47.

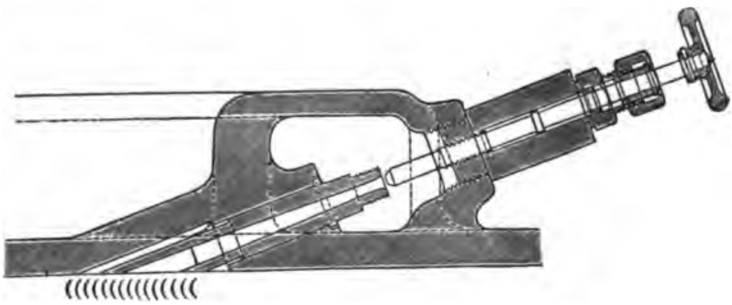


FIG. 47.—Nozzle and Valve in Messrs Greenwood and Batley's de Laval Turbine.

The largest sizes of de Laval turbines are generally furnished with eight nozzles.

The Flexible Shaft.—Of hardly less importance than the diverging nozzle is the use of the flexible shaft devised by de Laval to permit of operating with the very high speeds necessary with a single-wheel turbine. These very high speeds entail enormous centrifugal forces. Thus, from the data for the 300 horse-power turbine given in Table XXXII., we see that the addition of a weight of one gramme at the periphery of the wheel will subject it to an unbalanced centrifugal force of 47 kilograms. It is impracticable to deal by means of rigid shafts with such forces as are liable to be encountered in these cases, and hence de Laval employs a flexible shaft permitting the wheel to rotate about its centre of gravity in virtue of the gyrostatic effect. The wheel is not mounted midway between its bearings, but considerably nearer the spherical-seated outer bearing. When it is started up from rest, if its centre of gravity is not precisely in the axis of the

shaft, the shaft will bend as shown in Fig. 48, but, as there seen, the plane of revolution of the wheel is then no longer normal to the axis of rotation, and when a sufficiently high speed is reached the gyrostatic action is great enough to pull this plane back to a position normal to the axis of rotation, which requires the shaft to adapt itself to even rotation about the centre of gravity of the system. This occurs in virtue of the formation of a node at the centre of the hub of the wheel. The so-called "critical" speed is generally well below one-quarter of the normal speed.

The flexible shaft of a 100 horse-power size, with wheel and

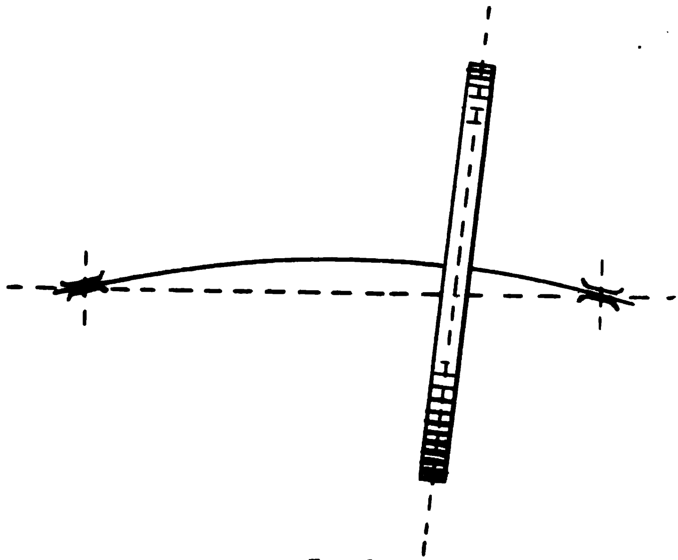


FIG. 48.

bearings, are shown in Fig. 49. Side by side with this, and approximately to the same scale, are shown the shafts for the 30 horse-power and 300 horse-power sizes.

Bearings.—Returning to the case illustrated in Fig. 49, which represents the Humboldt Company's method of construction, the bearing at the right-hand end is spherical-seated, so as to take up whatever end thrust may be exerted on the wheel by the impinging steam. This is very slight. As we have seen, the aim is to have the steam completely expanded to condenser pressure when it emerges from the nozzles, and hence the wheel runs in a medium of the low density corresponding to the condenser pressure, and the pressure should be the same on both sides of the wheel. As will be seen at A in Fig. 49, the bearing

is carried in a self-aligning spherical-seated casing, held inwards by a helical spring against its seat in the turbine casing.

On the other side of the wheel the shaft passes through a

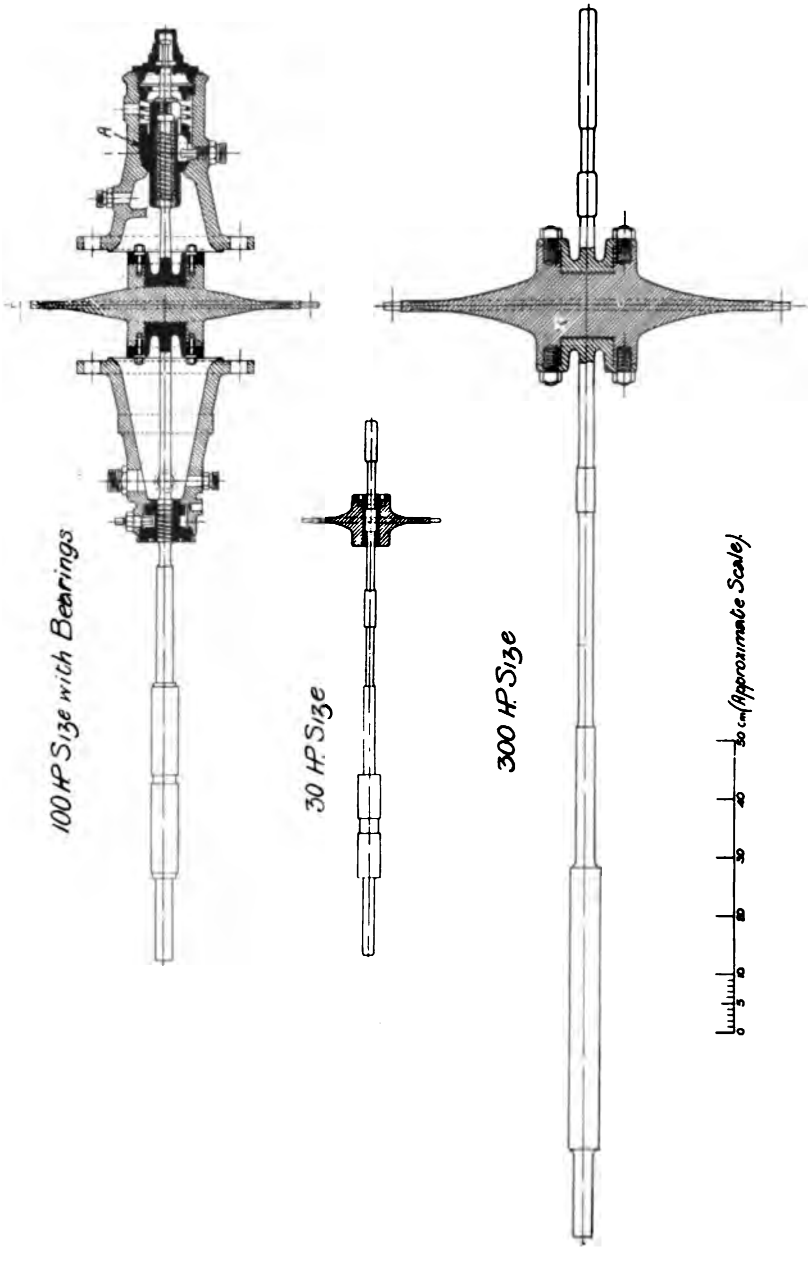


FIG. 49.—Shafts and Wheels of de Laval Steam Turbines.

loose-fitting bearing B, which serves primarily as a stuffing box. At either side of the pinions the shaft is carried in two bearings, which are best seen at C C in Fig. 41 p. 85.

Gears.—As already stated, the teeth of the pinions are cut directly on an extension of the flexible shaft, and are stated[1] to be "of ·60 or ·70 carbon steel." The gears are stated to be "of mild ·20 carbon steel, of a grade similar to that used for car wheel tyres." Up to and including the 30 horse-power size solid steel gears are employed, but for the larger sizes they have cast-iron centres and mild steel rims. The pitch of the teeth is about 3·8 millimetres in the smallest and some 6·6 millimetres in the largest sizes. It is stated in *Machinery* (p. 125, Nov. 1904) that "the success in running these gears at high speed is due in part to the fine pitch and the spiral angle of the teeth, which thus brings a large number of teeth in mesh at one time, making the working pressure at each tooth very light, and reducing the likelihood of abrasion." The gears run at the very high linear velocity of some 30 metres per second.

Table XXXIII. contains some interesting data of gears, pinions, shafts and bearings. The data in Table XXXIII. is only very rough, and has been compiled from a number of sources, the data in which was often more or less contradictory. The manufacturers are naturally averse to publishing precise data. Nevertheless, it is useful to have a general survey of the range of values employed. It is seen from Table XXXIII. that the speed of the flexible shaft at the bearing surface is in some cases over 20 metres per second.

The teeth of the pinions are cut at an angle of 45°, and, as indicated in Fig. 41, one of the pinions carries teeth cut on a left-handed and the other on a right-handed spiral. This prevents longitudinal motion.

Lubrication.—The low-speed bearings on each side of the gear wheels are provided with oil rings. The oil is distributed to the high-speed bearings by a shallow spiral groove (see Fig. 49) turned in the shell. In a 100 horse-power machine this groove is about 0·4 millimetre pitch. Sight feed lubricators are employed for the high-speed bearings. Lea and Meden state (*Trans. Am. Inst. Mech. Engrs.*, vol. xxv., 1904, p. 1064) that ring oiling has not proved to be satisfactory for the high-speed bearings. This, they say, is because "the turbine wheel shaft usually vibrates

[1] *Machinery* for Nov. 1904, "The de Laval Steam Turbine and its Manufacturers," p. 125.

TABLE XXXIII.—SOME DATA OF GEARS, PINIONS, SHAFTS AND BEARINGS

Rated Output of Turbine in H.P.	Rated Output of Turbine in K.W.	Country in which Turbine is Manufactured. S = Sweden | F = France | A = America. E = England | G = Germany	Rated Speed of Turbine Wheel in R.p.m.	Number of Teeth in Pinion.	Number of Teeth in Gear.	Gear Ratio.	Rated Speed of Dynamo in R.p.m.	Outside Diam. of Pinion in Millimetres.	Outside Diam. of Gear in Millimetres.	Depth of Teeth in Millimetres.
	..	..	..	..	..	..	..	..	..	..
	..	E	40,000	..	..	..	4,000	..	..	..
1·5	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	1·0	A	39,000	..	..	..	5,000	..	..	..
	..	..	..	..	..	..	..	..	..	..
	1·6	E	30,000	..	..	..	3,000	..	..	..
3	..	..	..	..	..	..	..	..	..	..
	..	G	30,000	..	..	..	..	..	..	..
	2	A	..	..	..	..	3,000	..	..	..
	..	..	..	..	..	..	..	..	..	..
	3·2	E	30,000	..	..	..	3,000	..	..	..
5	3·0	F	..	..	..	..	3,000	..	..	..
	..	G	30,000	..	..	..	..	..	..	..
	3·3	A	..	..	..	..	3,000	..	..	..
	..	..	..	..	..	..	..	..	..	..
	4·4	E	30,000	..	..	..	3,000	..	..	..
7	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	4·6	A	..	..	..	..	3,000	..	..	..
	..	..	..	..	..	..	..	..	..	..
	6·6	E	24,000	..	..	..	2,400	..	..	..
10	6·1	F	24,000	..	..	..	2.400	..	..	..
	..	G	24,000	..	..	..	..	..	..	..
	6·6	A	24,000	21	208	9·9	2,400	27·3	256	1·9
	..	..	..	..	..	..	..	..	..	..
	9·9	E	24,000	..	..	..	2,400	..	..	..
15	9·4	F	..	..	..	..	2,400	..	..	..
	..	G	24,000	..	..	..	..	..	..	..
	10·0	A	..	..	..	..	2,400	..	..	..

...f nozzles opened were in proportion to the load.

SOURCE OF DATA.
...*peur*, Paris, Ch. Beranger, 1904 (p. 151).
... special reference to the De Laval Type of Turbine," *Trans. Inst. Engrs.* ...vol. xlvi., Nov. 1902, page 25, part 1.
... special reference to the De Laval Type of Turbine," *Trans. Inst. Engrs.* ...vol xlvi., Nov. 1902, page 25.
...). London: Longmans, Green & Co., 1903.
...). London: Longmans, Green & Co., 1903.
... Turbine," *Amer. Soc. Mech. Engrs. Trans.*, vol. xxv. p. 1070.
do. do.
...*aval*, Paris, Ch. Dunod, 1902 (p. 16).
...*ur*, Paris, Ch. Beranger, 1904, p. 150.
...*ur*, Paris, Ch. Beranger, 1904, p. 152.

...Shaft at Gear Bearings in Metres per Second.
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Results for 120 per cent. of Rated Load. Admission Pressure (Absolute) Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Degrees Cent. Superheat at Admission.	Kgs. Steam Consumption per K. W. Hour Output from Dynamo.	Number of Nozzles Open.	Date of Test.	[1] No.
...	...	...	...	...	...	snowski, *Roues et Turbines*
...	...	...	...	...	Dec. 1899	ndersson, "Steam Turbines, *and Shipbuilders of Scotl*
...	...	...	...	...	June 1900	ndersson, "Steam Turbines, *and Shipbuilders of Scotl*
...	...	...	...	...	May and Jun 1902	eilson, *The Steam Turbine* (
...	...	...	...	...	May and Jun 1902	eilson, *The Steam Turbine*
...	...	...	...	..	...	ea & Meden, "The De Lav
...	...	...	...	...	...	Do.
...	...	...	...	...	...	Sosnowski, *Turbines à Vape*
...	...	...	...	...	...	Sosnowski, *Roues et Turbine*
..	...	...	...	...	1900	Sosnowski, *Roues et Turbin*

OF VARIOUS SIZES OF DE LAVAL TURBINES.

Rated Output of Turbine in H.P.	Peripheral Velocity of Teeth in Metres per Second.	Approximate Width of Gear Wheels at Teeth in Millimetres.	Rough Estimate of Diam. of Flexible Shaft at Thrust Bearing, in Millimetres. (This is identical with the Minimum Diam.)	Approximate Peripheral Speed of Flexible Shaft at Thrust Bearing in Metres per Second.	Rough Estimate of Diam. of Flexible Shaft at Pinion Bearings in Millimetres.	Approximate Peripheral Speed of Flexible Shaft at Pinion Bearings in Metres per Second.	Overall Length of Flexible Shaft in Millimetres.	Diam. of Secondary Shaft at Gear Bearings in Millimetres.	Peripheral Speed of Secondary Shaft at Gear Bearings in Metres per Second.
1·5	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
3	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
5	..	..	..	..	..	..	..	..	..
	..	..	5	7·9	10	15·8	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
7	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
10	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	5	6·3	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	32·3	..	..	..	..	..	..	..	..
15	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..

TABLE XXXIII.—*continued.*

Rated Output of Turbine in H.P.	Rated Output of Turbine in K.W.	Country in which Turbine is Manufactured. S=Sweden, E=England, F=France, G=Germany, A=America.	Rated Speed of Turbine Wheel in R.p.m.	Number of Teeth in Pinion.	Number of Teeth in Gear.	Gear Ratio.	Rated Speed of Dynamo in R.p.m.	Outside Diam. of Pinion in Millimetres.	Outside Diam. of Gear in Millimetres.	Depth of Teeth in Millimetres.
20	..	..	..	..	..	..	..	..	..	..
	13·2	E	20,000	..	..	..	2,000	..	..	..
	12·6	F	..	..	..	..	2,200	..	..	..
	..	G	20,000	21	208	9·9	2,000	..	..	..
	13·2	A	..	..	..	..	2,000	..	..	..
30	..	..	..	..	..	..	..	..	..	..
	20	E	20,000	..	..	..	2,000	..	..	..
	19·1	F	..	..	..	..	2,000	..	..	..
	..	G	20,000	..	..	..	..	..	..	..
	20	A	..	..	..	..	2,000	..	..	..
50	..	..	..	..	..	..	..	..	..	..
	33	E	16,400	..	..	..	1,500	..	..	..
	32·3	F	..	..	..	..	1,500	..	..	..
	..	G	15,000	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
55	..	..	..	..	..	..	..	..	..	..
	..	E	16,400	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	35	A	..	..	..	..	1,500	..	..	..
75	..	..	..	..	..	..	..	..	..	..
	50	E	16,500	..	..	..	1,250	..	..	..
	43	F	..	..	..	..	1,500	..	..	..
	..	G	15,000	..	..	..	..	..	..	..
	50	A	16,500	19	208	11·0	1,500	38·8	398	3·0
100	..	..	..	..	..	..	..	..	..	..
	..	E	13,000	..	..	..	1,250	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	G	12,500	..	..	..	..	..	568	..
	..	..	..	..	..	..	..	..	..	..

TABLE XXXIII.—*continued*.

Rated Output of Turbine in H.P.	Peripheral Velocity of Teeth in Metres per Second.	Approximate Width of Gear Wheels at Teeth in Millimetres.	Rough Estimate of Diam. of Flexible Shaft at Thrust Bearing in Millimetres. (This is identical with the Minimum Diam.)	Approximate Peripheral Speed of Flexible Shaft at Thrust Bearing in Metres per Second.	Rough Estimate of Diam. of Flexible Shaft at Pinion Bearings in Millimetres.	Approximate Peripheral Speed of Flexible Shaft at Pinion Bearings in Metres per Second.	Overall Length of Flexible Shaft in Millimetres.	Diam. of Secondary Shaft at Gear Bearings in Millimetres.	Peripheral Speed of Secondary Shaft at Gear Bearings in Metres per Second.
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
20	..	..	..	..	..	..	..	..	..
	..	150	11	11·5	18	18·8	1100	..	.
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
30	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	.
50	..	..	..	.	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	15	13·0	25	21·6	..	..	..
55	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
75	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	31·4	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
100	..	..	..	..	..	..	..	..	..
	..	300	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..

TABLE XXXIII.—*continued.*

Rated Output of Turbine in H.P.	Rated Output of Turbine in K.W.	Country in which Turbine is Manufactured. S=Sweden | F=France | A=America. E=England | G=Germany	Rated Speed of Turbine Wheel in R.p.m.	Number of Teeth in Pinion.	Number of Teeth in Gear.	Gear Ratio.	Rated Speed of Dynamo in R.p.m.	Outside Diam. of Pinion in Millimetres.	Outside Diam. of Gear in Millimetres.	Depth of Teeth in Millimetres.
110	..	..	..	..	..	..	..	..	..	..
	75	E	..	..	..	..	1,050	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	75	A	13,000	23	250	10·9	1,200	46·2	478	3·0
150	..	..	..	..	..	..	..	..	..	..
	100	E	13,000	..		..	1,050	..	..	..
	97	F	..	..	..	..	1,365	..	..	..
	..	G	12,600	..	..	..	..	..	..	..
	100	A	12,000	..	..	..	1,200	..	..	..
200	..	S	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	G	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
225	..	..	..	..	..	..	..	..	..	..
	150	E	11,000	..	..	..	1,000	..	..	..
	148	F	..	..	..	..	900	..	..	..
	..	G	12,000	..	..	..	..	..	..	..
	150	A	..	..	..	..	900	..	..	..
300	..	..	..	..	..	..	..	..	..	..
	200	E	10,600	..	..	..	750	..	..	..
	..	F	7,500	..	..	..	..	..	..	..
	..	G	10,500	..	..	..	..	..	..	..
	200	A	10,500	31	362	11·7	900	67·2	744	3·2
350	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	232	F	..	..	..	..	800	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..

TABLE XXXIII.—*continued.*

Rated Output of Turbine in H.P.	Peripheral Velocity of Teeth in Metres per Second.	Approximate Width of Gear Wheels at Teeth in Millimetres.	Rough Estimate of Diam. of Flexible Shaft at Thrust Bearing in Millimetres. (This is identical with the Minimum Diam.)	Approximate Peripheral Speed of Flexible Shaft at Thrust Bearing in Metres per Second.	Rough Estimate of Diam. of Flexible Shaft at Pinion Bearings in Millimetres.	Approximate Peripheral Speed of Flexible Shaft at Pinion Bearings in Metres per Second.	Overall Length of Flexible Shaft in Millimetres.	Diam. of Secondary Shaft at Gear Bearings in Millimetres.	Peripheral Speed of Secondary Shaft at Gear Bearings in Metres per Second.
110	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	30·0	..	..	..	..	..	..	..	..
150	..	..	..	..	..	..	..	..	..
	..	..	22	15·0	35	23·8	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
200	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	300	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
225	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
300	..	..	..	..	..	..	..	..	..
	..	..	30	16·6	42	23·3	..	..	..
	..	..	30	11·7	..	..	..	..	..
	..	500	..	..	..	..	..	..	..
	35·0	..	..	..	..	..	..	..	..
350	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..

slightly, and this vibration is communicated to the oil rings, which, refusing to follow the shaft, do not furnish proper lubrication.

"It is also found that the temperature of the oil will in this case increase too much, and drip lubrication has been found more satisfactory, only a small quantity of oil being required. With the high speed it is very important that the lubrication should not be interrupted, as it takes but a short time for the bearing to run hot. Wick lubrication has so far proved the most reliable. It must, however, be arranged so that the oil leaves the wick tube in drops, and with a sight glass below the tube through which the amount of feed can be ascertained. The oil is filtered by the wick, which ensures clean oil in the bearing, and the oil will flow as long as any oil remains in the tank. With oil tanks of ample size there will not be much attendance required. It seems, though, in the present advanced stage, that opposition is sometimes met with in having this method of lubrication used. The common sight-feed lubricator, with such a small number of drops as are required, has the disadvantage of a very small opening for the oil, so that a small amount of dirt will suddenly interrupt the lubrication. The bearings will then immediately heat. Any mechanical arrangement for forced lubrication is in itself more or less apt to get out of order. It is all right for slow-speed machinery, which, in case of interruption of the oiling, can run a considerable time on the oil already supplied, and until the trouble can be discovered and remedied, but it is more or less uncertain for high-speed apparatus."

The gears are continuously lubricated with a moderate amount of oil. They are encased as effectively as practicable to prevent the entrance of extraneous matter such as dust or grit. It is stated that with suitable care they will run for many years without visible wear. Lea and Meden state that the gear wheels were originally made of bronze, but it was found that they became crystallised after a couple of years of continuous operation, and pieces of teeth were broken off and destroyed the gears.

The enormous size of the speed-reduction gearing as compared with the size of the turbine itself is well shown in Fig. 41.

The centrifugal throttling governor and vacuum valve are illustrated in Figs. 51 and 50.

Fig. 50 shows the governor in section and shows the outside of the steam valve. The bell-crank lever L is fixed to a spindle which passes into the pipe and carries a straight lever inside the pipe (see Fig. 50) which operates the steam throttle valve. Fig.

51 shows the inside of the steam valve with the same bell-crank lever L dotted. It will be seen that there are two separate parts B B, mounted on knife edges A A, and held in place by the pressure of springs. The spring N balances the lever L. K is the end of the gear shaft which drives the governor. When the speed becomes sufficient for the weights B B to fly out by centrifugal force and overcome the resistance of the springs, through pins C C pressing against the collar D, rod G moves lever L,

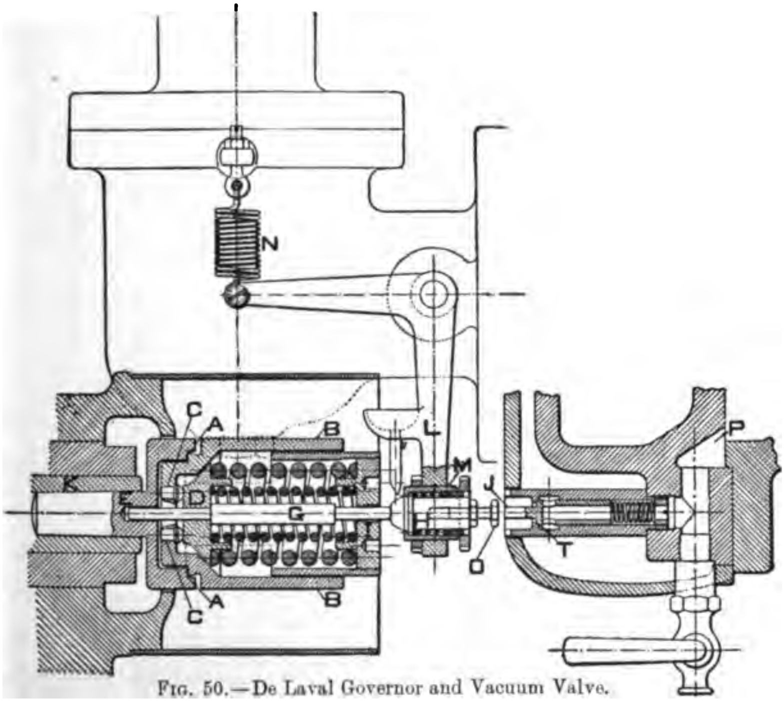


FIG. 50.—De Laval Governor and Vacuum Valve.
(C. Garrison, *Techn. Quarterly*, March 1904.)

which has a certain "play" in M, and definitely reduces the opening of the valve in Fig. 51.

A travel of only one-eighth of an inch of the plunger covers the valve's motion from full-open to definitely-closed.

With condensing de Laval turbines a vacuum valve T is arranged in connection with the governor, so that in case of the turbine exceeding a predetermined speed limit and the steam throttle valve failing, the vacuum is destroyed by the governor pressing on this valve and admitting air to the condenser through passage P. The steam consumption non-condensing is so much

greater than when condensing that it is impossible for full steam supply (valves fully open) to give excessive speed.[1]

Overload Capacity of the de Laval Turbine.—This is largely dependent upon the number of nozzles with which the turbine is equipped. It is customary to supply the turbine with sufficient nozzle capacity to carry continuously at least 10 per cent. overload. If, however, a heavier overload capacity is desired, it can be provided by substituting suitable nozzles, and it is sometimes required that the machine shall carry at least 25 per

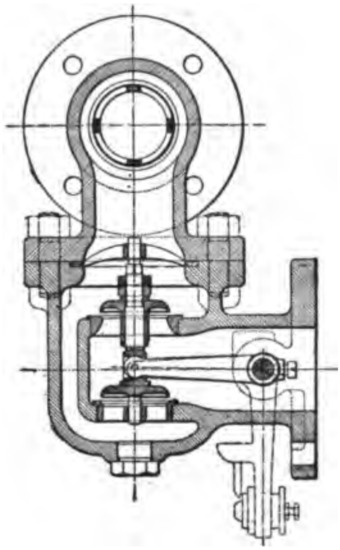
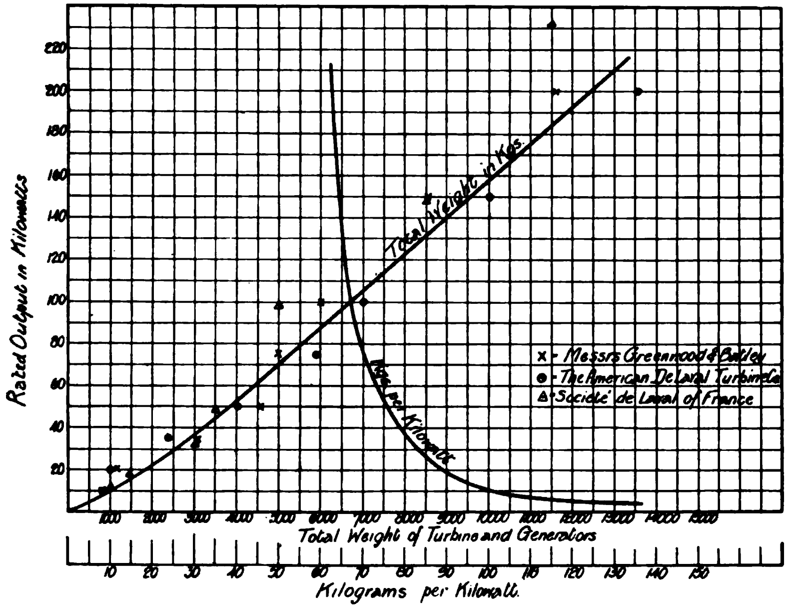
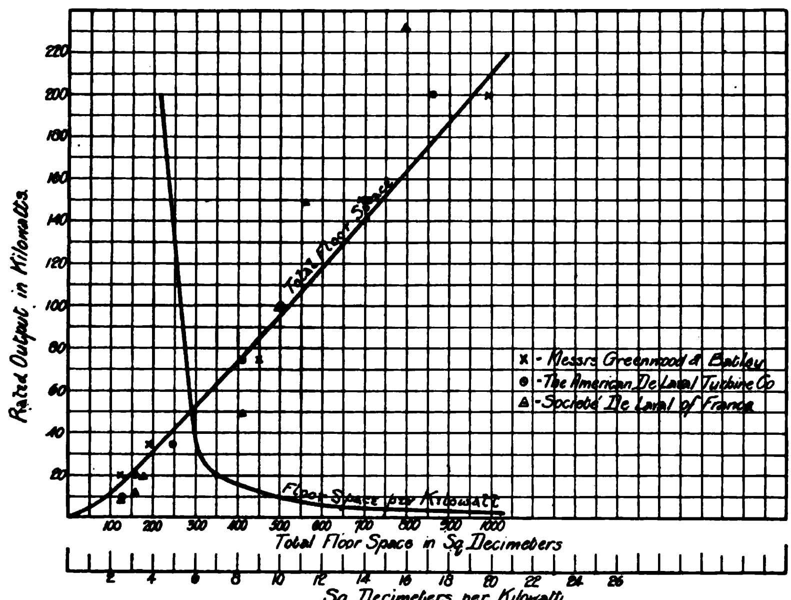


FIG. 51.—Governor Valve.

cent. overload for fairly long periods continuously. In such cases the turbine case is generally fitted with one nozzle in addition to the usual number, this being opened only when the overload comes on. If a heavier overload than one for which the nozzles are designed comes on, the speed falls off. The same size, weight, and general design of turbine is employed for a given output, whether for running condensing or non-condensing. The only difference relates to the design of the nozzles. In small turbines, which are required to run either condensing or non-condensing, two entirely different sets of nozzles are provided for

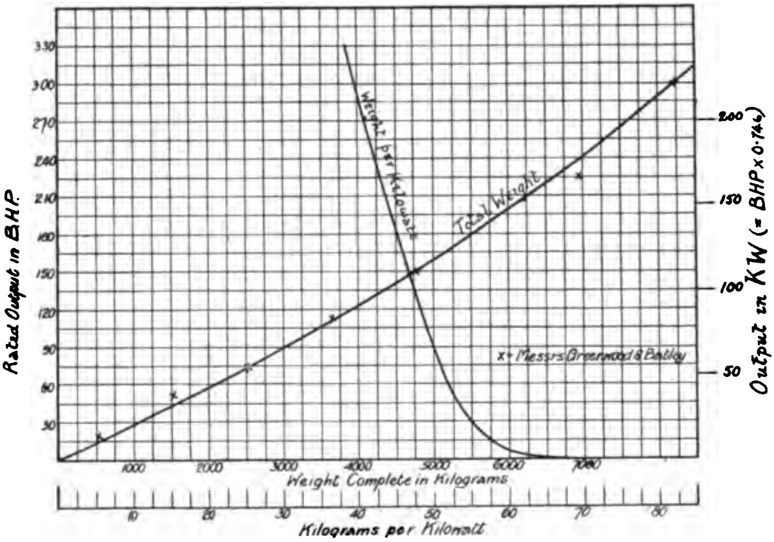
[1] Mr Charles Garrison, S.B., in *Proceedings of the Society of Arts, Mass. Inst. of Tech.*, March 1904, stated :—" that a 150 h.p. condensing turbine would not come up to rated full-load speed when run non-condensing with all nozzles open and with no load."

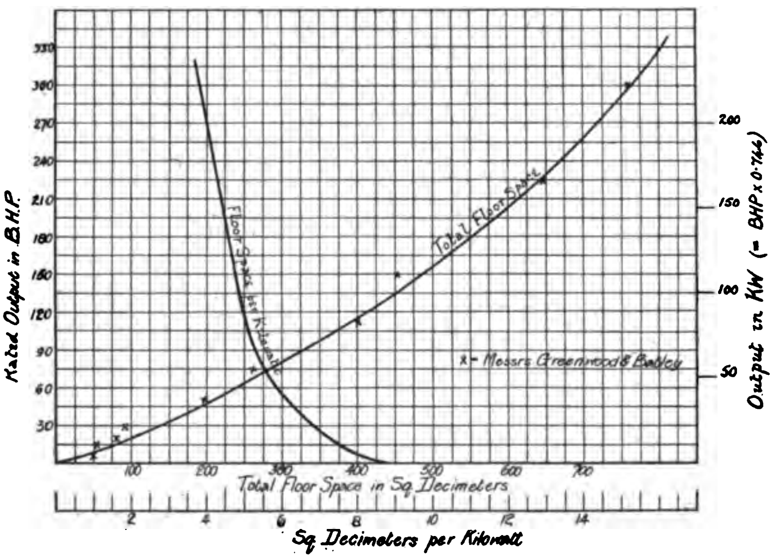




FIGS. 52 and 53.—De Laval Turbines and Generators. Approximate Weight and Floor Space.

Direct Coupled Sets.





FIGS. 54 and 55.—De Laval Steam Turbines. Approximate Weight and Floor Space of Turbines.

For Rope or Belt Driving.

in the turbine case. Each nozzle has a shut-off valve, and the condensing nozzles are opened when the turbine is operated, exhausting into an independent condenser, the non-condensing nozzles then being closed, and *vice versa* when the turbine is running non-condensing. Each of these two sets of steam nozzles has sufficient capacity for driving the turbine continuously with full load, and each set is constructed to carry the same overload.

In the design and rating of direct coupled generating sets, the practice of the different manufacturers of de Laval turbines in different countries varies to a certain extent. Table XXXIV. has been compiled from rough data given in various publications. The purpose of the table is merely to give a general idea of customary practice, and is not to be taken as necessarily correct in special cases. For instance, the weights of the complete sets were often given, and in other sections the weights of turbines alone. From these we have deduced the weights of the dynamos, and we have not attemped to investigate the discrepancies revealed by this rough method of analysis.

These dimensions have been taken from publications of various firms, and any apparently wide divergences are probably due to some dimensions being taken just over the bed plate, and others over the actual greatest over-all length of the machine.

In Figs. 52 to 55 are plotted curves showing the variation of weight and floor space, with output for combined turbo-generating sets and for turbine motors. Figs. 52, 53, relating to turbo-generators, show respectively the total weight and weight per kilowatt-rated output plotted against output. Figs. 54 and 55 are similar curves for turbine motors for rope or belt driving.

Machines of different manufacture are indicated on the curves by various styles of points, and smooth curves have been drawn through these points, giving a sufficiently good idea of the range of values.

[TABLE XXXIV.

TABLE XXXIV. (A1).

Rated Output of Turbine in H.P.	Rated Output of Turbine in K.W.	Country in which Turbine is Manufactured. S=Sweden, E=England, F=France, G=Germany, A=America.	Rated Speed of Turbine Wheel in R.p.m.	Continuous Current Turbine Sets. Rated Speed of Shaft or Shafts of Dynamo or Dynamos in R.p.m.	No. of Dynamos per Turbine.	Total Weight of Dynamo or Dynamos in Kilograms.	Total Weight of Turbine, including Gearing, in Kilograms.	Total Weight of Complete Set in Kilograms.	Total Weight of Complete Set per Rated Kilowatt in Kilograms.	Kilowatts per Vane.	Approximate Overall Length in Metres.
	..	..	..	..	..	..	..	..	..	..	..
	1·0	E	40,000	4,000	1	36	76	112	112	..	·71
1·5	..	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..
	1·0	A	39,000	5,000	1	..	..	112	112	..	·76
	..	..	..	..	..	..	..	..	..	..	..
	1·6	E	30,000	3,000	1	73	102	175	110	..	1·0
3	..	..	..	..	..	..	..	..	..	..	..
	..	G	30,000	3,000	1	..	100	..	..	..	..
	2	A	..	3,000	1	..	..	214	107	..	1·1
	..	..	..	..	.	..	..	..	..	..	..
	3·2	E	30,000	3,000	1	221	165	386	120	0·07	1·3
5	3·0	F	..	3,000	1	210	150	360	120	..	1·3
	..	G	30,000	3,000	1	..	175	..	..	..	..
	3.3	A	..	3,000	1	..	..	386	117	..	1·25
	..	..	..	..	..	..	..	..	..	..	..
	4·4	E	30,000	3,000	1	201	204	405	92	..	1·42
7	.	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..	..
	4·6	A	..	3,000	1	..	..	410	89	..	1·27
	..	..	..	..	..	..	..	..	..	..	..
	6·6	E	24,000	2,400	1	435	255	690	105	..	1.63
10	6·1	F	24,000	2,400	1	365	225	590	97	..	1·52
	..	G	24,000	2,400	1	..	325	..	..	..	..
	6 6	A	24,000	2,400	1	..	..	710	108	..	1·52
	..	..	..	..	..	..	..	..	..	..	..
	9·9	E	24,000	2,400	1	510	280	766	80	..	1·7
15	9·4	F	..	2,400	1	440	260	700	75	..	1·66
	..	G	24,000	2,400	1	..	330	..	..	..	..
	10·0	A	..	2,400	1	..	..	790	79	0·09	1·6

TABLE XXXIV. (A2).

Rated Output of Turbine in H.P.	Continuous Current Sets. Approximate Overall Width in Metres.	Area of Floor Space occupied in Sq. Dcms.	Floor Space in Sq. Dcms. per Kilowatt Rated Output.			Alternating Current Turbine Sets (Excluding Exciters). Speed of Alternator or Alternators in R.p.m.	No. of Poles per Alternator.	Periodicity in Cycles per Second.	Type.	No. of Phases.	Rated Output in Kilowatts. Cos $\phi=1{\cdot}00$	Cos $\phi=0{\cdot}80$
	..	..	..			..	..	..	..	..	..	..
	29	20	20			..	..	..	..	..	..	..
1·5	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·28	22	22			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·36	36	22·5			..	..	..	..	..	..	..
3	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	.	..	..	..
	·42	47	23·5			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·41	54	17·0			..	..	..	..	..	..	..
5	·57	74	24·6			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·56	70	21·0			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·41	58	13·2			..	..	..	..	..	..	..
7	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·56	71	15·5			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·51	83	12·6			..	..	..	..	..	..	..
10	·64	97	15·9			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	.	..
	·64	97	14·7			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·51	87	8·8			..	..	..	..	..	..	..
15	·74	123	13·1			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·66	106	10·6			..	..	..	..	..	..	..

TABLE XXXIV. (A3).

Rated Output of Turbine in H.P.	Alternating Current Turbine Sets (Excluding Exciters).									
	Voltage.	No. of Alternators per Turbine.	Total Weight of Alternator or Alternators in Kilograms.	Total Weight of Turbine, including Gearing, in Kilograms.	Total Weight of Complete Set in Kilograms.	Total Weight of Complete Set per Rated Kilowatt in Kilograms.	Approximate Overall Length in Metres.	Approximate Overall Width in Metres.	Area of Floor Space occupied in Sq. Dcms.	Floor Space in Sq. Dcms. per Kilowatt Rated Load.
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
1·5	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
3	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	...	..	.	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
5	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
7	..	..	..	..	..	..	.	..	..	.
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	.	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
10	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
15	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..

TABLE XXXIV. (B1).

Rated Output of Turbine in H.P.	Rated Output of Turbine in K.W.	Country in which Turbine is Manufactured. S = Sweden, E = England, F = France, G = Germany, A = America.	Rated Speed of Turbine Wheel in R.p.m.		Continuous Current Turbine Sets.									
						Rated Speed of Shaft or Shafts of Dynamo or Dynamos in R.p.m.	No. of Dynamos per Turbine.	Total Weight of Dynamo or Dynamos in Kilograms.	Total Weight of Turbine, including Gearing, in Kilograms.	Total Weight of Complete Set in Kilograms.	Total Weight of Complete Set per Rated Kilowatt in Kilograms.	Kilowatts per Vane.	Approximate Overall Length in Metres.
	..	..	..			..	..	..	..	..	..	..	..
	13·2	E	20,000			2,000	1	430	540	970	74	..	2·2
20	12·6	F	..			2,200	1	580	420	1,000	80	..	1·8
	..	G	20,000			2,000	1	..	570	..	..	..	..
	13·2	A	..			2,000	1	..	..	960	73	0·15	1·9
	..	..	..			..	..	..	..	..	..	..	..
	20	E	20,000			2,000	1	710	560	1,270	64	..	2·3
30	19·1	F	..			2,200	1	870	580	1,450	76	..	1·92
	..	G	20,000			2,000	1	..	660	..	..	..	..
	20	A	..			2,000	1	..	..	1,270	64	..	1·93
	..	..	..			..	..	..	..	..	..	..	..
	33	E	16,400			1,500	2	1,720	1,480	3,200	97	..	2·4
50	32·3	F	..			1,500	2	1,490	1,570	3,060	95	..	2·12
	..	G	15,000			1,500	2	..	1,890	..	..	..	..
	..	..	..			..	..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..	..
	..	E	16,400			..	..	..	..	..	..	..	...
55	.	..	..			..	..	..	..	.	..	..	..
	..	..	..			..	..	..	..	..	..	..	..
	35	A	..			1,500	2	..	..	2,280	65	..	2·44
	..	..	..			..	.	..	..	..	..	..	..
	50	E	16,500			1,250	2	1,680	2,550	4,230	85	..	2·74
75	48	F	..			1,500	2	1,530	1,870	3,400	71	..	2·61
	..	G	15,000			1,250	2	..	2,630	..	..	..	..
	50	A	16,[illegible]00			1,500	2	..	..	4,100	82	..	2·62
	..	..	..			..	..	..	..	..	..	..	..
	..	E	13,000			1,250	..	..	..	..	..	..	..
100	..	F	..			..	..	..	..	..	..	..	..
	..	G	12,600			1,050	2	..	3,900	..	..	..	..
	..	..	..			..	..	..	..	..	..	..	..

TABLE XXXIV. (B2).

Rated Output of Turbine in H.P.	Continuous Current Sets. Alternating Current Turbine Sets (Excluding Exciters).											
	Approximate Overall Width in Metres.	Area of Floor Space occupied in Sq. Dcms.	Floor Space in Sq. Dcms. per Kilowatt Rated Output.			Speed of Alternator or Alternators in R.p.m.	No. of Poles per Alternator.	Periodicity in Cycles per Second.	Type.	No. of Phases.	Rated Output in Kilowatts. Cos φ = 1·00	Rated Output in Kilowatts. Cos φ = 0·80
20	..	..	..			..	..	..	..	..	..	..
	·67	147	11·1			..	..	..	..	..	..	..
	·86	155	12·3			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·79	150	11·4			..	..	..	..	..	..	..
30	..	..	..			..	..	..	..	..	.	..
	·67	154	7·7			..	..	..	..	..	..	..
	·92	176	8·8			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·87	167	..			..	..	..	..	..	..	..
50	..	..	..			..	..	..	..	..	..	.
	·92	220	6·8			..	..	..	..	..	..	..
	1·43	310	9·6			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
55	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	·99	241	6·9			..	..	..	..	..	..	..
75	..	..	..			..	..	..	..	..	..	..
	1·04	279	5·6			..	..	..	..	..	..	..
	1·59	415	8·6			..	..	..	..	..	..	..
	..	..	.			..	..	..	..	..	..	..
	1·20	314	6·3			..	..	..	..	..	..	..
100	..	..	..			..	..	..	..	..	..	..
	..	..	.			..	..	..	..	..	..	..
	..	..	..			1500	4	50	..	..	..	66
	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	.	..	..

TABLE XXXIV. (B3).

Rated Output of Turbine in H.P.	Alternating Current Turbine Sets (Excluding Exciters). Voltage.	No. of Alternators per Turbine.	Total Weight of Alternator or Alternators in Kilograms.	Total Weight of Turbine, including Gearing, in Kilograms.	Total Weight of Complete Set in Kilograms.	Total Weight of Complete Set per Rated Kilowatt in Kilograms.	Approximate Overall Length in Metres.	Approximate Overall Width in Metres.	Area of Floor Space occupied in Sq. Dcms.	Floor Space in Sq. Dcms. per Kilowatt Rated Load.
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
20	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
30	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
50	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
55	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
75	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
100	..	2	..	..	4800	78	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..

TABLE XXXIV. (C1).

Rated Output of Turbine in H.P.	Rated Output of Turbine in K.W.	Country in which Turbine is Manufactured. S = Sweden | F = France | A = America. E = England | G = Germany	Rated Speed of Turbine Wheel in R.p.m.			Continuous Current Turbine Sets. Rated Speed of Shaft or Shafts of Dynamo or Dynamos in R.p.m.	No. of Dynamos per Turbine.	Total Weight of Dynamo or Dynamos in Kilograms.	Total Weight of Turbine, including Gearing, in Kilograms.	Total Weight of Complete Set in Kilograms.	Total Weight of Complete Set per Rated Kilowatt in Kilograms.	Kilowatts per Vane.	Approximate Overall Length in Metres.
110	..	..	..			..	..	..	..	..	..	..	..
	75	E	..			1,050	2	..	..	5,100	68	..	3·20
	..	..	..			..	..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..	.
	75	A	13,000			1,200	2	..	..	5,900	79	..	2·97
150	..	..	..			..	..	..	..	..	..	..	..
	100	E	13,000			1,050	2	1,000	4,800	5,800	58	..	3·47
	97	F	..			1,365	2	2,600	2,400	5,000	52	..	2·9
	..	G	12,600			1,050	2	..	4,950	..	..	..	..
	100	A	12,000			1,200	2	..	..	7,300	73	..	3·49
200	..	S	..			..	..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..	..
	..	F	..			..	..	..	..	..	..	..	..
	..	G	..			..	..	..		..	..	..	..
	..	..	..			..	..	..	..	..	..	..	..
225	..	..	..			..	..	..	..	..	..	..	..
	150	E	11,000			1,000	2	1,650	7,000	8,650	58	..	4·15
	148	F	..			900	2	3,800	4,700	8,500	58	..	3·5
	..	G	12,000			1,000	2	..	6,000	..	..	..	..
	150	A	..			900	2	..	..	10,500	70	..	3·94
300	..	..	..			..	..	..	..	..	..	..	..
	200	E	10,600			750	2	3,500	8,200	11,700	58	..	4·73
	..	F	7,500			..	..	..	..	..	..	..	..
	..	G	10,500			750	2	..	10,400	..	..	..	..
	200	A	10,500			900	2	..	..	13,600	68	0·10	4·57
350	..	..	..			.	..	..	..	...	..	..	..
	..	..	..			..	..	..	..	..	..	..	..
	232	F	..			800	2	3,550	7,950	11,500	50	..	4·16
	..	..	..			..	..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..	..

TABLE XXXIV. (C2).

Rated Output of Turbine in H.P.	Continuous Current Sets.					Alternating Current Turbine Sets (Excluding Exciters.)						
	Approximate Overall Width in Metres.	Area of Floor Space occupied in Sq. Dcms.	Floor Space in Sq. Dcms. per Kilowatt Rated Output.			Speed of Alternator or Alternators in R.p.m.	No. of Poles per Alternator.	Periodicity in Cycles per Second.	Type. I.R.F. = Int. Rev. Field.	No. of Phases.	Rated Output in Kilowatts. Cos φ = 1·00	Rated Output in Kilowatts. Cos φ = 0·80
	..	..	..			..	..	..	..	..	..	..
	1·43	455	6·1			..	..	..	..	..	..	..
110	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	1·40	415	5·5			1200	6	60	I.R.F.	2 or 3	75	..
	..	..	..			..	..	..	..	..	..	..
	1·43	500	5·0			..	..	..	..	..	..	..
150	1·7	493	5·1			1000	6	5	..	..	..	100
	..	..	..			..	..	..	..	..	..	..
	1·42	496	5·0			1200	6	6	I.R.F.	2 or 3	100	..
	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
200	..	..	..			1000	6	50	..	..	..	132
	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	1·65	685	4·6			..	..	..	..	..	..	..
225	1·59	556	3·8			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	1·80	710	4·7			900	8	60	I.R.F.	2 or 3	150	..
	..	..	..			..	..	..	..	..	..	..
	2·10	990	4·9			..	..	..	..	..	..	..
300	..	..	..			750	8	50	..	..	..	200
	..	..	..			..	..	..	..	..	..	..
	1·9	868	4·3			900	8	60	I.R.F.	2 or 3	200	..
	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
350	1·91	795	3·4			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..
	..	..	..			..	..	..	..	..	..	..

TABLE XXXIV. (C3).

Rated Output of Turbine in H.P.	Alternating Current Turbine Sets (Excluding Exciters). Voltage.	No. of Alternators per Turbine.	Total Weight of Alternator or Alternators in Kilograms.	Total Weight of Turbine, including Gearing, in Kilograms.	Total Weight of Complete Set in Kilograms.	Total Weight of Complete Set per Rated Kilowatt in Kilograms.	Approximate Overall Length in Metres.	Approximate Overall Width in Metres.	Area of Floor Space occupied in Sq. Dcms.	Floor Space in Sq. Dcms. per Kilowatt Rated Load.
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
110	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	220 to 3000	2	..	..	5500	74	3·18	1·3	415	5·5
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
150	..	2	3800	2400	6200	62	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	220 to 3000	2	..	..	7450	75	3·48	1·37	476	4·76
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
200	..	2	..	..	7500	57	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
225	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	220 to 3000	2	..	..	11600	77	3·8	1·65	676	4·2
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
300	..	2	..	..	10000	50	..	..	..	..
	..	..	...	..	..	..	..	..	..	..
	220 to 3000	2	..	..	14400	72	4·1	2·3	943	4·7
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
350	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..	..

CHAPTER IV

THE PARSONS TURBINE

PARSONS' early contributions to steam turbine development date from practically the same period as de Laval's, and it is only in the interests of lucidity that we have given first place to a discussion of the de Laval turbine; for the Parsons turbine, as regards both construction and operation, is considerably less simple than the de Laval turbine.

Passing over the historical development of the Parsons type of turbine and coming to the modern machine, it should first be pointed out that turbines differing in many respects from one another, but all possessing the main features of the Parsons type, are now being built by a number of more or less independent manufacturers. Most of the sets at present installed have been built by one or the other of the three following concerns:— Messrs C. A. Parsons & Co., Newcastle-on-Tyne; Messrs Brown, Boveri & Co., Baden, Switzerland; The Westinghouse Companies, of Pittsburg, Pa., U.S.A., and Manchester, England. A large number of other companies have also taken out licenses to manufacture Parsons turbines, but sufficient time has as yet hardly elapsed to permit of reporting progress in these quarters.[1]

The development of the Parsons turbine for marine purposes is referred to in a later chapter. In the present chapter land turbines only will be discussed.

The turbines built by Messrs C. A. Parsons & Co. and those by Messrs Brown, Boveri & Co. are very similar, and will be referred to as Parsons turbines. The modifications made by the Westinghouse Co. are more extensive, although the main principles

[1] The Brush Co. has sent us particulars of one of their designs (see Fig. 58, facing p. 122).

of the Parsons type are retained; they have expanding nozzles at the high-pressure end.

In the Parsons turbine, so-called stationary 'guide vanes' are employed instead of the diverging nozzles of the de Laval turbine to direct the steam against the vanes of the running wheel. It is not attempted in these guide vanes to transform the energy of the steam completely into kinetic energy (*i.e.* energy of translational motion), and on emerging from the guide vanes the energy of the steam is only partly kinetic. That portion which is kinetic is more or less completely imparted to the vanes of the moving wheel, according to very much the same general principles described in Chapter III. on the de Laval turbine. A further part of the energy of the steam emerging from the guide vanes is employed to drive forward the vanes of the moving wheel by expansion. A third portion is passed on to the next set of vanes, imbued with a diminished store of energy. A leading characteristic of the Parsons turbine, as compared with the de Laval type, thus relates to the employment of many stages in the former as against one stage in the latter. For this purpose the Parsons turbine is built with a very large number of sets of fixed vanes alternating with a corresponding number of sets of vanes mounted on the periphery of a rotating drum. Whereas in the de Laval type, in which the steam is, in the diverging nozzle, already expanded down to the pressure in the condenser, in consequence of which the wheel revolves in a medium of very low density and with an approximately equal pressure on each side of the wheel, the wheel of the Parsons turbine rotates in a medium having a high density at the admission end and a very low density at the exhaust end. Not only would this, for a given peripheral speed, necessitate considerably higher friction of the wheel aganst the medium in which it revolves, but there is the further disadvantage that there is a leakage of steam, increasing with the clearances between the rotating and stationary parts. Hence it would be expected that it would be very desirable in turbines of the Parsons type to employ a minimum of clearance. Furthermore, there is an end pressure acting in the direction of flow of the steam from the admission to the exhaust end. The end pressure is offset by the use of so-called 'balance pistons,' connected with a suitable number of points along the cylinder by means of passages cored out in the casing.

In Figs. 56, 57, and 58 are shown sections through the

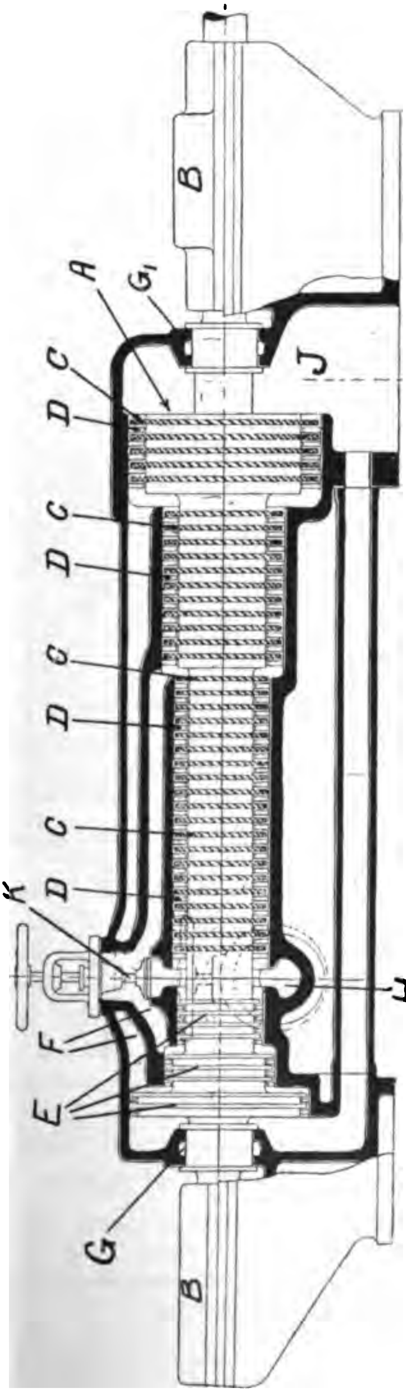


FIG. 56.—Longitudinal Section through a Brown Boveri-Parsons Turbine.

cylinders of three designs of Parsons turbine, and in Fig. 59 are shown in plan and elevation the outlines of a direct-connected turbo-generating set. These have been furnished us through the courtesy of Messrs Brown, Boveri & Co., the Westinghouse Co., and the Brush Co., and admirably serve the purpose of explaining the Parsons type. The turbine rotor A (Figs. 56, 57, and 58) consists of a long drum, supported in bearings at B B. At the periphery of the rotor are carried the vanes C, arranged in a

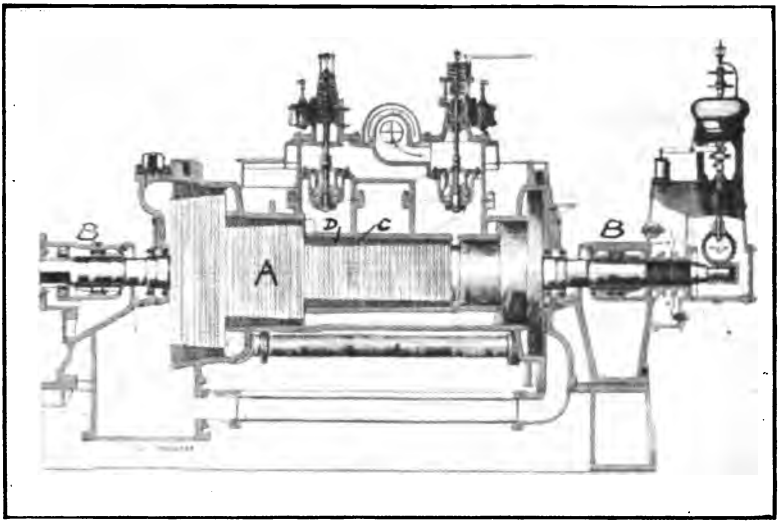
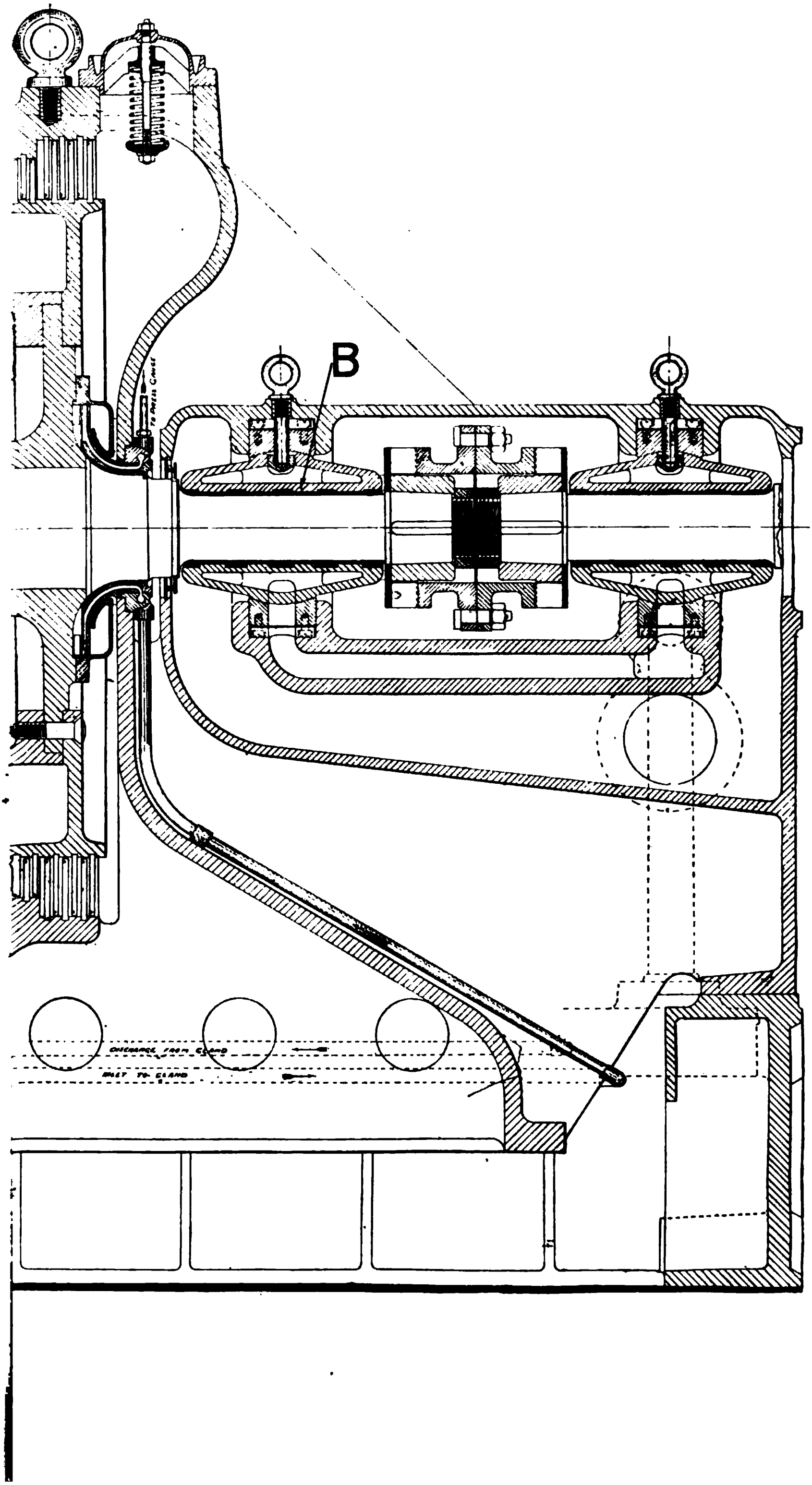


FIG. 57.—Westinghouse-Parsons Steam Turbine.

number of rings varying according to the output, speed, and required economy. In the 400 kilowatt Westinghouse-Parsons turbine illustrated in Fig. 60, with the top half of the casing removed, there are 116 rings of vanes, 58 of these being on the rotor. The total number of vanes in the Parsons type is enormous (see Table XXXVI., p. 154). Thus in a 750 kilowatt turbine there are stated to be some 15,000 revolving vanes and an equal number of fixed vanes, making a total of 30,000 vanes. This is 20 rotating vanes per kilowatt, or 0·050 kilowatts per rotating vane.[1] Between the rings of rotating vanes are the

[1] The 2000 kilowatt Westinghouse-Parsons turbine installed at the Yoker station of the Clyde Valley Power Co. are stated to have "over 20,000" vanes, presumably on the rotor. This gives 0·10 kilowatt per rotating vane. It has also been stated that in a certain Westinghouse-Parsons 500 kilowatt turbine there are 16,000 rotating and 16,000 fixed vanes, or 0·031 kilowatt per rotating vane.

[*To face page* 122.



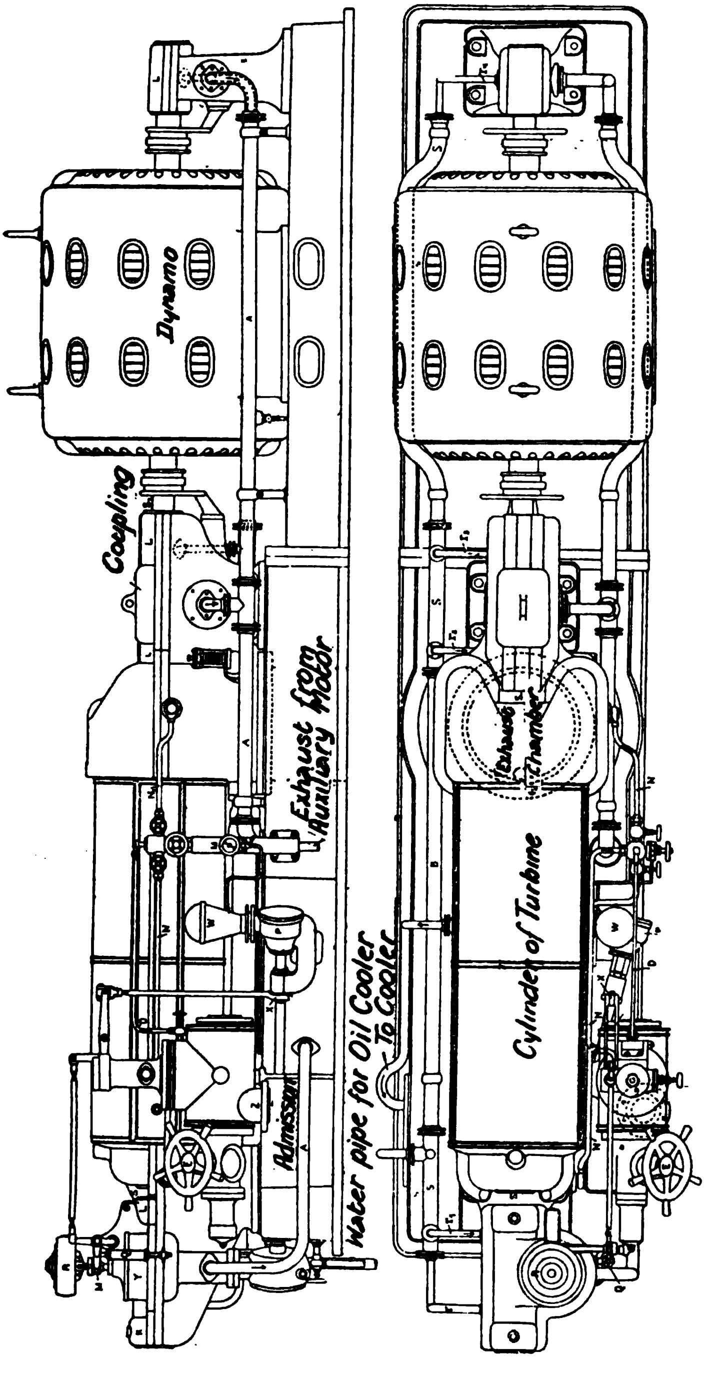


FIG. 59.—Parsons Turbine and Direct-Coupled Dynamo-Plan and Elevation.

stationary vanes D (Fig. 56). The contour and relative position of the fixed and rotating vanes are indicated in Fig. 61. Going from the high-pressure to the low-pressure end of the turbine, the

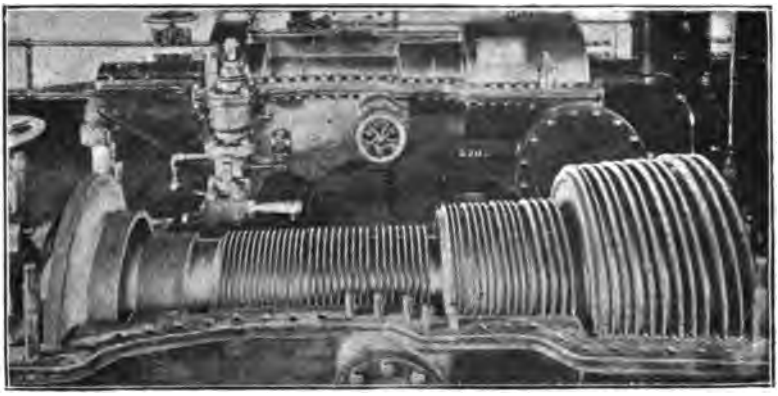


FIG. 60.—400 K.W. Westinghouse-Parsons Turbine, uncovered. (J. R. Bibbins, *The Electric Journal*, June 1905.)

rings increase in diameter. Thus in the design illustrated in Fig. 56 three different diameters are employed. In the Westinghouse-Parsons 400 kilowatt turbine, illustrated in Fig. 60, there is a still larger number of different diameters. The increase in

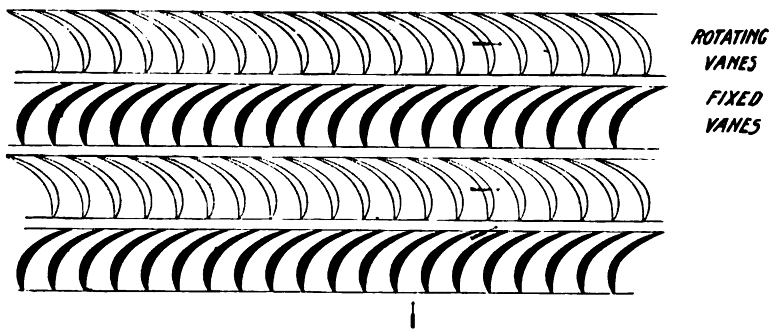


FIG. 61.—Diagram of Brown Boveri-Parsons Vanes.

diameter of the drum is also accompanied by an increase in radial length of the rotating and fixed vanes. This is most clearly shown in the turbine illustrated in Fig. 62, in which one readily distinguishes, from an examination of the top half of the casing, that there are seven different lengths of vanes. There is also an

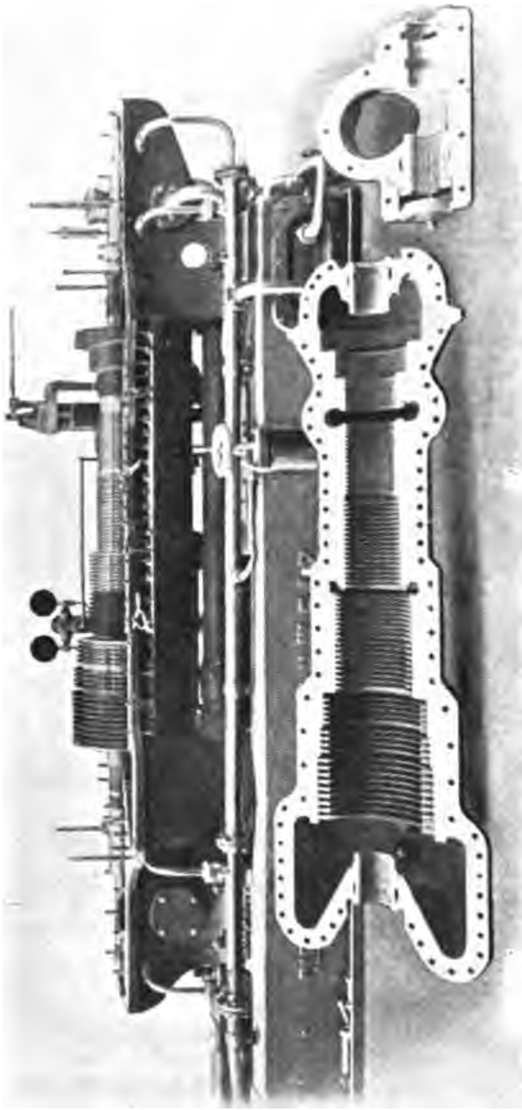


FIG. 62.—Brown Boveri-Parsons Turbine, open.

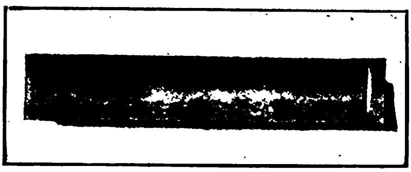
accompanying increase in the width of the vanes. Musil states[1] that in a 750 kilowatt turbine set, which, from an analysis of his

[1] *Bau der Dampfturbinen*, A. Musil, p. 102 (Leipzig, B. G. Teubner), 1904.

data, appears to have a speed of 1500 revolutions per minute, the proportions are approximately as follows :—

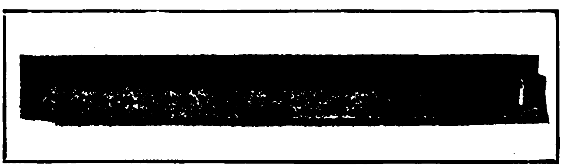
	First Row.	Last Row.
Diameter to middle of radial depth of vane	400 mm.	900 mm.
Peripheral speed in metres per sec. . .	31	70
Pitch at diameter to middle of radial depth of vane.	5 mm.	15 mm
Width of vane in direction parallel to shaft	10 mm.	20 mm.
Radial length of vane	10 mm.	150 mm.
No. of vanes per ring	251	188

From this data the total number of rings of vanes on the rotor appears to be about 68.



8th Row, half size.

Section, 1½ actual size.



11th Row, half size.

FIG. 63.—400 K.W. Westinghouse-Parsons Turbine Low-Pressure Vanes.
(J. R. Bibbins, *The Electric Journal*, June 1905.)

Photographs of low-pressure rotor vanes of the 400 kilowatt Westinghouse-Parsons turbine, already illustrated in Fig. 60, are shown in Fig. 63. Vane A corresponds to the eighth and vane B to the eleventh row. The section of the vane is illustrated by the photograph in Fig. 63. The vanes are of bronze, and are rolled in long rods and afterwards cut up into suitable lengths. It is stated by Musil (*Bau der Dampfturbinen*, p. 103) that when

high superheat is employed, the vanes of the first rings are of rolled copper, presumably owing to the lower coefficient of expansion of copper. The same author states that the stress per vane is scarcely 0·2 kilogram at full load, and Messrs Brown, Boveri & Co. state that a factor of safety of from 20 to 40 is employed.

Slots, slightly narrower at the surface than inside, are turned in the periphery of the drum. Into these the vanes are put singly. Next to each vane comes a wedge of brass, and the vanes and wedges are caulked so as to fill up the dovetail. The dovetail is necessary for providing the support for resisting the centrifugal

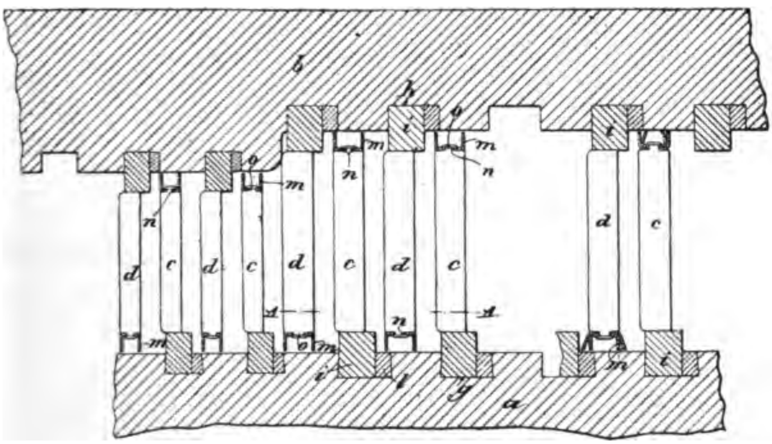


FIG. 64.—Longitudinal Section of part of Drum and Casing, *with combined Fitting and Baffling Rings.* (H. F. Fullagar, 21932 (1903).)

force on the rotating vanes. The stationary vanes fixed inside the casing, not being subjected to centrifugal force, require no dovetail. The outer ends of the long vanes at the low-pressure end are bound together with wire, which is soldered to the vanes. In some cases the vanes are turned at the outer end, thus providing a flange, which is soldered into a complete shroud.

In some recent cases all the vanes in each ring are bound together[1] with wire at their outer ends. This includes fixed vanes as well as revolving vanes.

The following method is due to H. F. Fullagar, and is covered by Patent No. 21932 (1903). Figs. 64 to 68 and 76 illustrate the

[1] "In the 4000 kilowatt sets at Carville it has been considered necessary to lace all the blades in both high and low pressure chambers, and on both stator and rotor" (*Electrician*, vol. 57, p. 426, July 1st, 1904).

method of fixing the blades by Fullagar's construction. Fig. 64 is a longitudinal section through part of the drum and casing of a turbine, and Fig. 65 is a section through the line A A. Fig. 66 is a

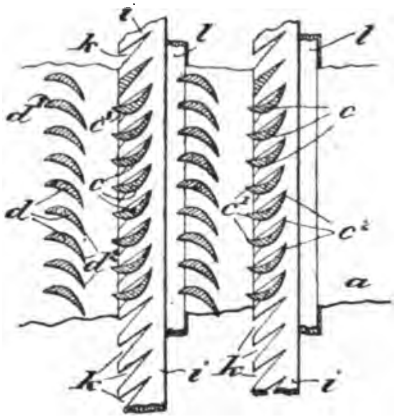


FIG. 65.—Developed Section on A A, Fig. 64.

perspective view of a portion of a ring of blades adapted for fixing in a groove on the rotor drum, and Fig. 67 shows a single detached blade. *a* represents the rotary drum, and *c* the rotating blades;

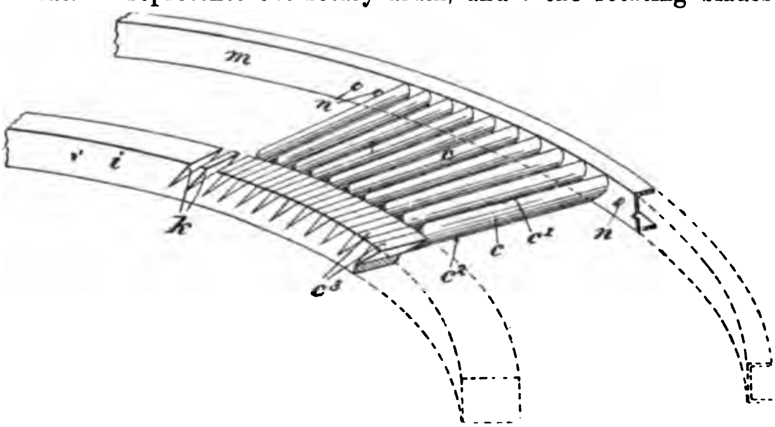


FIG. 66.—Perspective View of Ring of Blades in an Annular Groove in Rotary Spindle of a Turbine.

while *b* represents the stationary case, and *d* the fixed blades. The blades *c* and *d* are cut from a strip of rolled or drawn metal of the required crescent-shaped section; the root end is flattened to a wedge shape by pressure between special dies, as shown at C_3. The drum *a* and casing *b* have grooves *g* and *h*, in which are rings

of brass i. In the flat side of these rings are cut wedge-shaped notches k, into which fit the wedge ends of the blades, which latter are secured firmly by a caulking strip l, caulked into the groove alongside the strip i. The upper ends of the blades are completely encircled by what is designated a "combined fitting and baffling ring," shown at m in the figures.

These rings are of thin metal of channel section, or two channels one within the other, and are formed with perforations n, pitched at the required distance to receive projections o on the outer ends of the blades, to which the rings m are secured. Leakage of steam is prevented by the close proximity of the baffling rings and the un-slotted faces of the rings i.

It is claimed that by the means described the rings of blades will be rendered strong and light, and can be easily, quickly, and cheaply machined to fit the casing and spindle or drum.

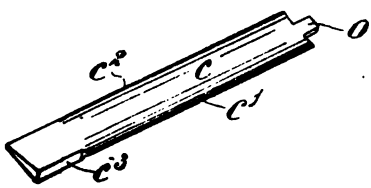


FIG. 67.—C^1 is inlet edge, C^2 is outlet edge.

Fig. 68 shows the appearance of a portion of the finished blading on the turbine shaft.

Messrs Brown, Boveri & Co. state that there is a clearance of from 3 to 4 mm., in a direction parallel to the shaft, between the fixed and moving vanes, and a radial clearance of from 2 to 3 mm. between the extremities of the moving blades and the inner walls of the casing. It is stated that, in spite of allegations to the contrary, it has been found that these comparatively large clearances do not entail any appreciable sacrifice in economy.

The chief consideration underlying the employment of many stages is, that it permits of a reduction of the speed of the turbine, as expressed in revolutions per minute, together with a further reduction in the peripheral speed. It might, with a fair approximation to the truth, be said that it permits of a reduction in the magnitude of the product of these two quantities. This is, of course, very desirable, since not only does it avoid the necessity of resorting to speed-reduction mechanisms, but it permits of restricting the stresses in the material of the rotating wheel to values not very greatly in excess of those heretofore customary in machine design.

Theorising aside, it appears in practice to be fairly conclusively established that the modern examples of large Parsons turbines show an excellent steam economy, in spite of the possibly more rational lines on which it is maintained that some of the more recent types have been designed. In fact, it is the contention of the advocates of the Parsons type that it excels precisely in virtue of the employment of the impact and reaction principles in such combination as to obtain the maximum resultant of advantages. By means of the large number of stages, the diameters of the

FIG. 68.—Willans-Parsons Turbine.
Fixed and Moving Vanes.

wheels are so greatly reduced as to largely offset the tendency to increased friction loss due to rotation in a medium of rather high average density. Whereas the peripheral speed employed in the largest size of the de Laval type amounts to 425 metres per second, the peripheral speed employed by Messrs Parsons rarely exceeds 125 metres per second, even in their largest sets, which are of several thousand kilowatts rated capacity. Considerably smaller peripheral speeds are employed in their smaller sets.

The balance pistons, to which reference has already been made on p. 120, are shown at E E E of Fig. 56, three sets being employed in this design. The passages cored out in the casing, and communi-

cating with the balance pistons, are indicated at F F F. In some designs (especially for large sizes), some of these cored-out passages are replaced by pipes external to the casing. This plan is adopted in the Westinghouse-Parsons design illustrated in Fig. 57, p. 122. Annular grooves in the rims of the balance pistons admit annular projections from the casing. This labyrinth construction is found to effectually prevent undue leakage of steam past the balance pistons. The small leakage of steam actually occurring is drained off to the condenser through the pipe F′. A similar construction is employed to prevent leakage at G G′ where the shaft emerges from the casing. At G′, at the low-pressure end, steam is led to the annular groove, to more effectually prevent the entrance of air. There are thus in the Parsons turbine no rubbing surfaces exposed to steam.

The steam is admitted at the high-pressure end H (Fig. 56), and after following, parallel to, but spirally about, the shaft in its course past the fixed and movable vanes, arrives at the outlet J, leading to the condenser. On occasions when the turbine must temporarily operate non-condensing, the valve K is opened, and the steam is admitted direct to an intermediate stage of the turbine. This enables the turbine to carry its load, though, of course, at the cost of an increased steam consumption, as expressed in kilograms of steam per kilowatt-hour of output.

Messrs Parsons have used, for turbines of over 2000 revolutions per minute, and up to 800 horse-power, a design of flexible bearing to reduce the effect on the foundations of any vibration in the shaft, and to permit the rotor to revolve about the centre of gravity.

This main bearing consists of four concentric bronze bearing liners, with 0·1 millimetre (0·004 inch) clearance between each pair, and with provision for supplying oil between each pair. This gives several films of oil to provide cushioning when vibration occurs, and to accomplish the purpose for which de Laval used a flexible shaft, that is, to allow for the unavoidable slight difference between the centre of gravity and centre of rotation.

In larger machines which run at lower speeds, such good results have been accomplished in balancing that the ordinary single spherical-seated white-metal-lined shell is used. This type is cooled with water from a low-pressure supply.[1]

[1] The quantity of water varies, according to the size of turbine, from ½ litre to 3 litres per second (or 400 to 2400 gallons per hour) (*Bau der Dampfturbinen*, A. Musil, p. 109).

Bearing Pressure.—The product of peripheral velocity, in feet per second and pressure in pounds per square inch, is generally 2500 (in some cases 3000),[1] according to London, and in a 1000 kilowatt Brush-Parsons turbine, the rotor of which weighs 6300 lbs., this product is 1500.[2]

Thrust Bearing.—Fig. 69 shows clearly the method of adjusting the position of the moving vanes with reference to the fixed vanes. The lower half of the bearing is fixed and the collars on the shaft are in contact on their left side in the figure, while the upper half is adjustable along the shaft and takes the thrust

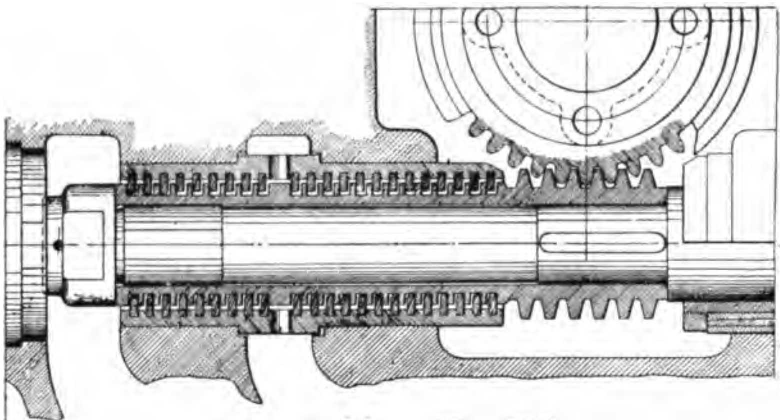


FIG. 69.—Brush-Parsons Thrust Blocks.
W. Chilton, Inst. E.E. Mchr., Feb. 2, 1904.

on the opposite side of these collars. It is thus evident that the shaft cannot move either to the right or the left.

Regulator.—A simple and ingenious piece of mechanism is employed to control the quantity of steam admitted according to the load on the turbine.

Messrs Brown, Boveri & Co.'s construction is illustrated in Fig. 70.

The admission of steam into the turbine is not continuous, but consists of a series of intermittent admissions of steam (gusts), at regular intervals, at a frequency of about 150 to 250 per minute, according to the size of the turbine. The duration of each of these gusts is controlled by the regulator, and is longer or shorter according to the load.

[1] "Mechanical Construction of Steam Turbines," W. A. J. London, *Proc. Inst. Elec. Engrs.*, vol. 35, p. 189, June 1905.

[2] "The Steam Turbine," W. Chilton, Manchester Local Section, *Proc. Inst. Elec. Engrs.*, vol. 33, p. 587, February 2nd, 1904.

The steam enters through a valve V, which is given a vertically oscillating motion, and which for heavy loads, and corresponding steam consumptions, remains at each admission raised for a longer time than it remains on its seat, thus admitting more steam, and *vice versa* for light loads. This is accomplished thus:—

The opening and closing of the valve V is controlled by a small piston B mounted above the valve. On the lower face of this piston the steam pressure acts, while it tends to stay at the

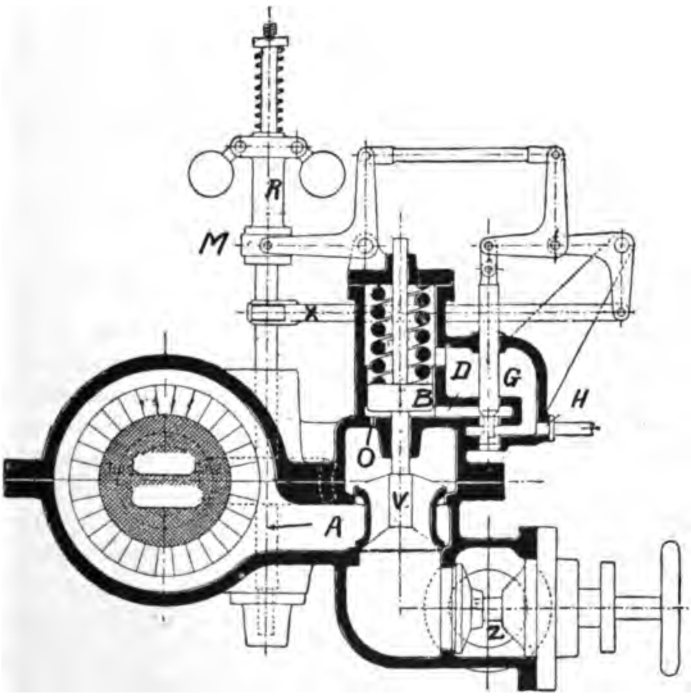


FIG. 70.—Brown Boveri-Parsons.

lower end of its cylinder by action of a strong spring pressing on its upper face.

An auxiliary valve with spindle G, possessing an oscillatory movement from an eccentric X (Figs. 70 and 59), causes the lower face of the piston B to communicate with the exhaust, and thus the valve V falls again to its seat.

The spindle G of this auxiliary valve is linked up to the muff M of the ball governor R, which latter thus augments or diminishes the amplitude of the oscillations of the valve G, and in consequence causes the valve V to open a longer or shorter time

after its closing. This arrangement allows of a very sensitive regulation of the steam admitted, always at full pressure, according to the load.

Figs. 71, 72 show three curves illustrative of the action of this regulator, published by Messrs Brown, Boveri & Co.

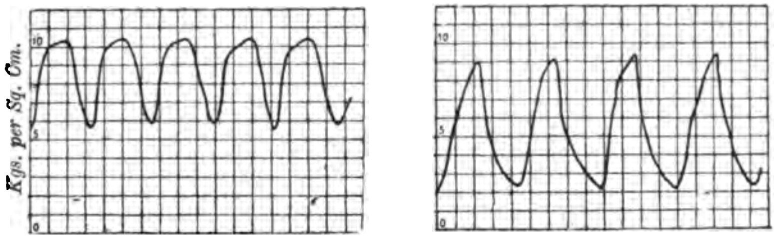


FIG. 71.—Admission Pressure Diagrams, Condenser Pressure being 0·9 Kg. per Sq. Cm.

Curve A shows the pressure at the turbine for full load, curve B at half load, and C shows the effect of a sudden change from three-quarters of full load to no load. The point brought out by these curves is the duration of each period of admission of steam, which they show to be greatest at full load, less at three-quarter and half loads, and very small at no load.

The fact that the no-load curve does not rise to near the

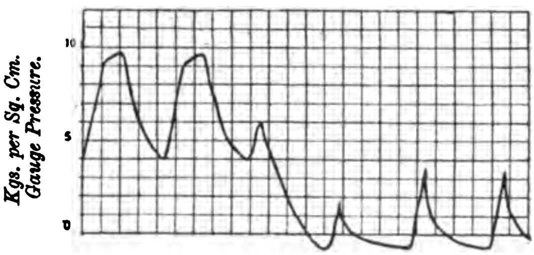


FIG. 72.—Diagram of Admission Pressure during Sudden Change in Load.

maximum pressure of about 10 kilogram per sq. cm. is most likely due to the sluggishness in the recording apparatus for such a very short interval of time as the period of steam admission at no load.

Lubrication.—Rotary oil-pressure pumps, driven in most instances from the turbine shaft, supply a constant flow of lubricant under a pressure of 30 lbs. per square inch or less, depending on the size of the unit.

The consumption of oil for different sizes of Parsons turbines may be summarised thus:—

TABLE XXXV.

Rated Horse-power.	Total Consumption of Lubricating Oil.		
	Gms. per hour.	Gms. per H.p. hour.	Lbs. per 1000 H.-p. hours.
100	30	·3	·66
1500	150	·1	·22
5000	250	·05	·11

A Brown-Boveri-Parsons turbo-dynamo is illustrated in Fig. 73, and index letters are placed adjacent to the various parts.

In Fig. 74 is shown a 3200 kilowatt Brown-Boveri-Parsons three-phase 4-pole generating set, installed at the Frankfort Electricity Works. The set runs at 1360 revolutions per minute, the periodicity being 45·3 cycles per second. It has a length of 16·5 metres and a maximum width and height of 2·5 metres. The performance of this set is shown by the tests in section xx. of Table XXXVII., on p. 156. The turbine has two casings, for the high and low pressure sections respectively. This construction permits of employing an extra bearing midway along the length of the shaft.

Another photograph of this same set, taken while it was under test at the manufacturers' works, is reproduced in Fig. 75.

The largest set as yet undertaken by Messrs Brown, Boveri & Co. is that for the Electricity Works at Essen. The normal rating of the turbine is 10,000 horse-power, and this power is employed in driving two generators,—one an alternator of 5000 kilowatt rated capacity, and the other a continuous-current dynamo of 1500 kilowatt rated capacity. The turbine itself is about 7 metres long. The complete set, including the dynamos, is 18 metres long and 3 metres high. Its total weight is 180,000 kilograms.

The 5500 kilowatt Westinghouse-Parsons turbo-generating sets, of which eight sets[1] have been installed at the Chelsea power-house of the Underground Electric Railways Co. of London, differ considerably in appearance from the designs of Messrs Brown, Boveri & Co. and Messrs C. A. Parsons & Co. This difference is chiefly attributable to the plan of admitting the steam to the cylinder at a point midway between bearings, and letting it flow

[1] The completed power station will contain ten of these 5500 kilowatt sets and an auxiliary 2750 kilowatt unit.

in opposite directions through the cylinders, the steam ultimately flowing off from both ends to the condenser. This construction

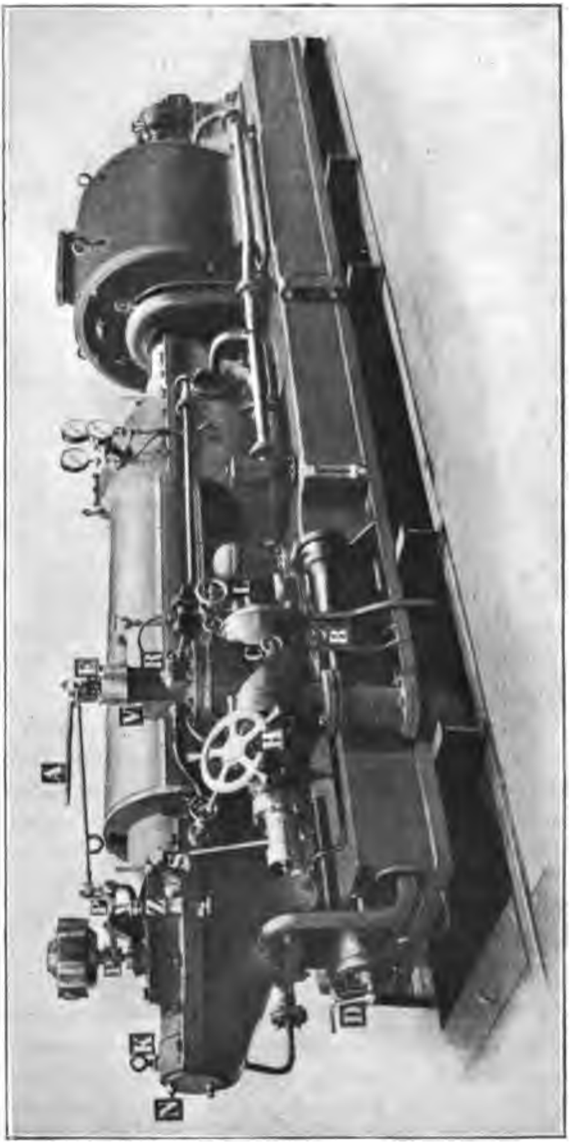


Fig. 73.—Brown Boveri-Parsons Set.

A = lever for opening valve on starting.
B = oil pump.
C = chamber containing admission valve.
D = crank for pumping oil by hand before starting.
E = throttle.
H = hand wheel to main admission valve.
K = thrust bearing.
L = air chamber for equalising oil pressure.
M = exciter (at right-hand end of figure).
N = cover.
P = governor.
Z = adjustable spring regulator.

eliminates end thrust, and obviates the necessity of employing balance pistons. The design is shown in plan and elevation in Figs. 383, 384, pp. 540, 541.

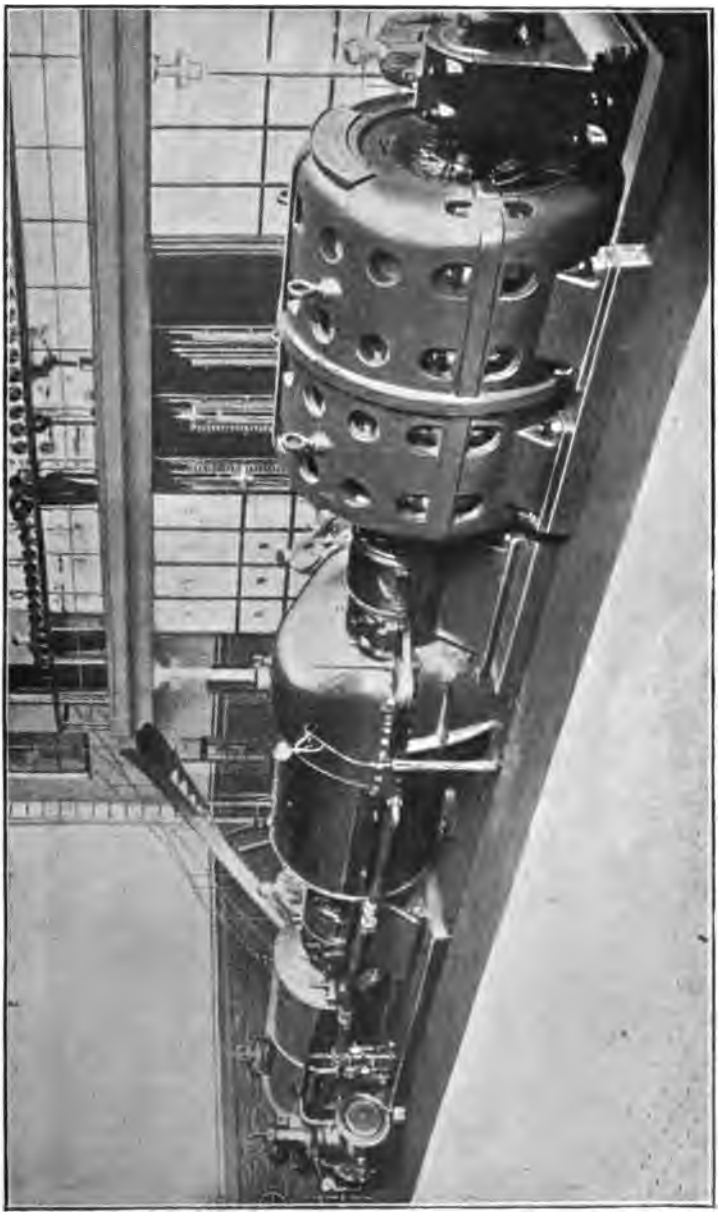


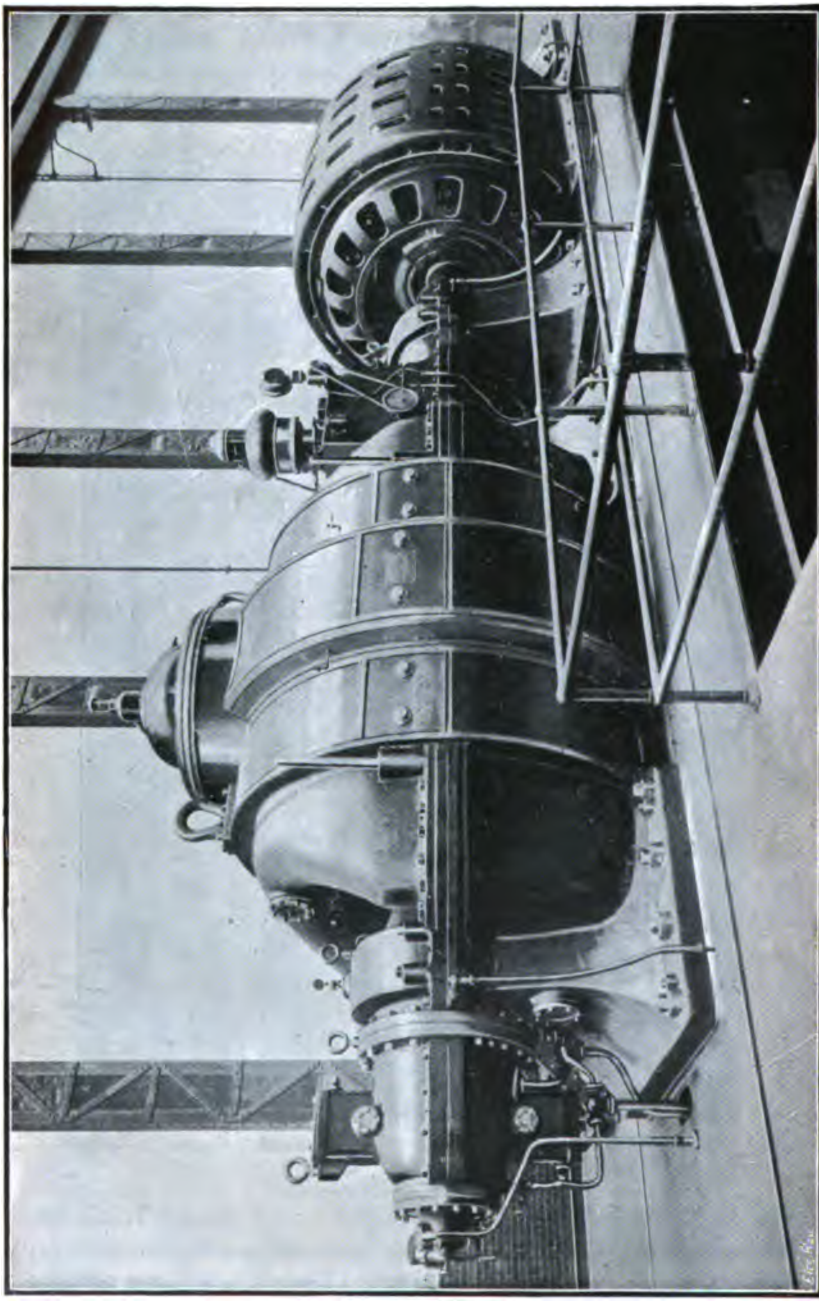
Fig. 74.—3200 K.W. Brown Boveri-Parsons Set at Frankfort.

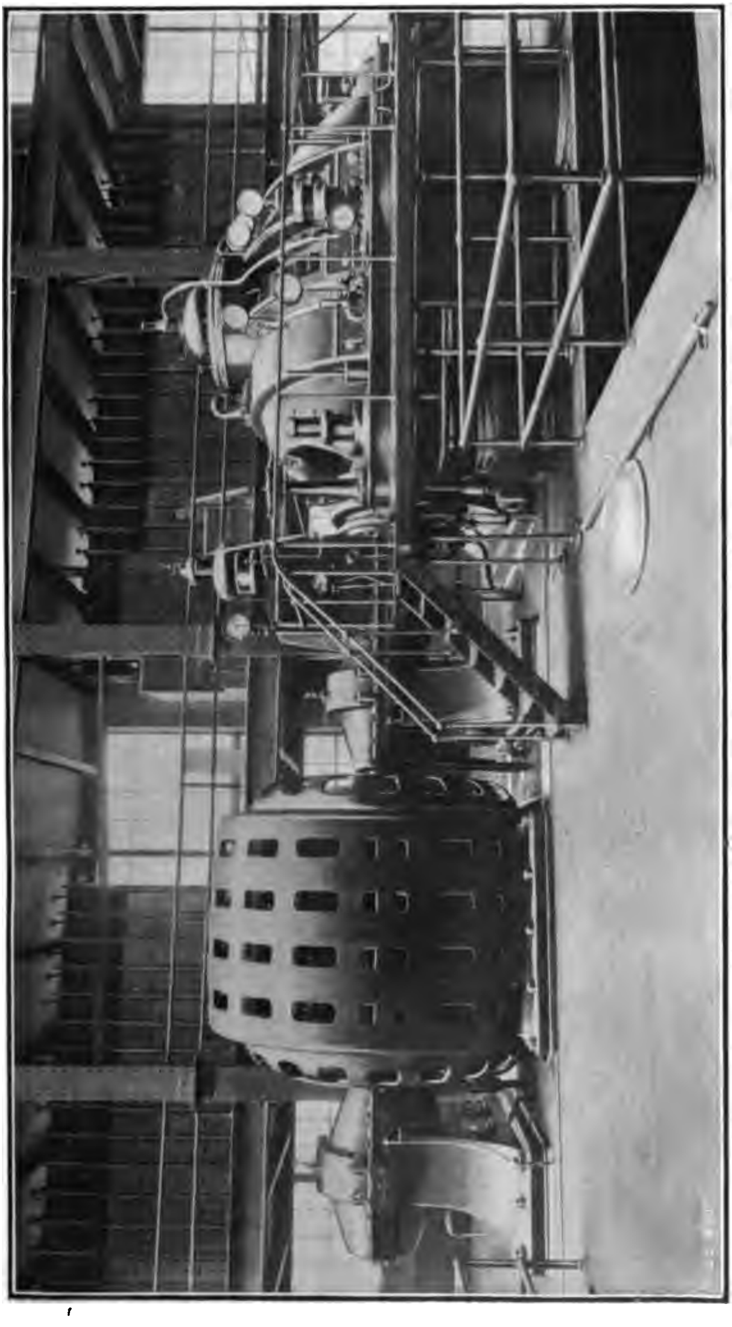
FIG. 75.—3200 K.W. Steam Turbo-Generator, Frankfort.

The photographs in Figs. 77, 78, and 79 give an excellent idea of the appearance of the sets as installed. Fig. 79 gives a view of the inside of the lower half of the casing, and shows the stator blades in place. Fig. 80 is a photograph of the rotor, and

FIG. 76.—Willans-Parsons-Fullagar Shrouded Vanes.

Fig. 81 shows the turbine cases under construction. These sets run at 1000 revolutions per minute, supplying current at 33-1/3rd cycles per second and 11,000 volts. The generators have four poles. The turbines are described by the Westinghouse





FIGS. 77 and 78.—Two Views of 5500 K. W. Westinghouse-Parsons Set.

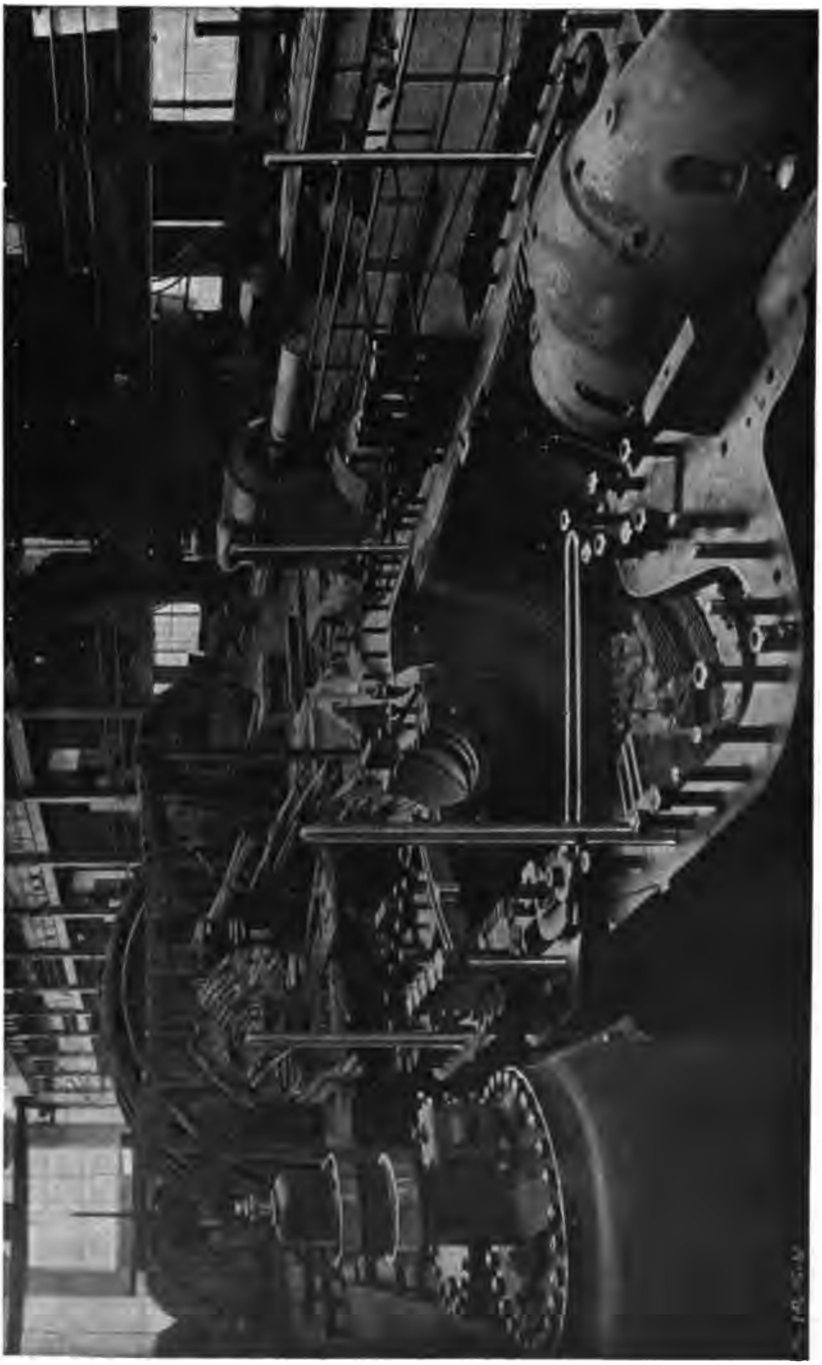


FIG. 79.—5500 K.W. Lower Half of Turbine Case with Fixed Vanes.
(Photo by *Tramway and Railway World*.)

Co. as being of the single-cylinder double-flow type. They are designed for an absolute admission pressure of 12·7 kilograms per square centimetre, with a superheat of 55·5° Cent. and with a vacuum of from 86·6 per cent. to 90 per cent. (*i.e.* 26″ to 27″).

Fig. 80.—Rotor, 5500 K.W.

The steam consumption under these conditions was stated to be 'approximately' as follows:—

Output.	Kgs. Steam per K.W.H.	
	86·6 per cent. vacuum.	90 per cent. vacuum.
$1\frac{1}{4}$ load (6875 K.W.) .	9·8	8·3
Full load (5500 K.W.) .	9·5	8·05
$\frac{3}{4}$ load (4125 K.W.) .	10·5	9·2
$\frac{1}{2}$ load (2750 K.W.) .	11·25	9·8

These figures are not test results, but are evidently guarantees.

On the basis of these figures, the velocity of steam in the pipe leading to turbine works out at about 8 metres per second (1600 feet per minute) at full load, and 4·8 metres per second (960 feet per minute) at half load. For the similar 3500 kilowatt sets at Neasden (Metropolitan Railway) the steam velocity works out at about 9·4 metres per second (1850 feet per minute). The

Fig. 81.—Preparing to bore out Turbine Cases.

sets are capable of sustaining an overload of 50 per cent. by the aid of automatic by-passes.

The steam first passes through the main 'disc type' stop valve, which is controlled from the platform by a hand wheel through gearing. It then flows through an emergency shut-down valve, a strainer, and a double-seated poppet governor valve, the latter being operated by a steam relay controlled by the centrifugal governor, this admission valve being thereby directly controlled by the speed of the turbine.

At the end of the shaft opposite to that at which the centrifugal governor is attached is fitted an emergency governor; this latter acts if the speed of the turbine rises to a predetermined maximum and the centrifugal governor fails from any cause, opening an auxiliary valve, which in turn closes the emergency throttle valve.

After entering at the centre of the cylinder, the steam next passes through a series of nozzles and impulse blades, this operation being repeated until the steam has expanded approximately to atmospheric pressure. Then the steam passes through a series of pressure blades "on the Parsons principle"[1] until the exhaust is reached. A thrust block is fitted at the extreme end of the cylinder, but as there is no end thrust, owing to the use of the 'double-flow' design, this is only required for the longitudinal adjustment of the rotor.

The rotor is constructed as a rolled steel drum with a diameter of 1·95 metres, thus giving a peripheral speed at the root of the vanes of 103 metres per second. A forged-steel umbrella-shaped disc is shrunk into each end, and at the same time the ends of the high-carbon steel shaft are pressed into these discs, thus giving a very light and strong construction. The construction is stated to have the advantage of 'virtually' eliminating the balancing difficulties met with in cast-steel and other non-homogeneous materials. The material can be depended upon for uniform density throughout, and by machining it to gauge a perfect balance should be obtained. The first series of blades are of drop-forged steel, and are dovetailed in form, and are caulked into grooves cut in the surface of the cylinder. The low-pressure blades are made of delta metal, in order to avoid any corrosion due to wetness of the expanding steam.

It is stated that the combination bed plate of each turbo-generator weighs about 52,000 kilograms (52 tons).

[1] *The Tramway and Railway World*, February 1905.

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This same double-flow design is employed in the three-phase, 25 cycle, 2000 kilowatt, 1500 r.p.m., 11,000 volt turbo-generating

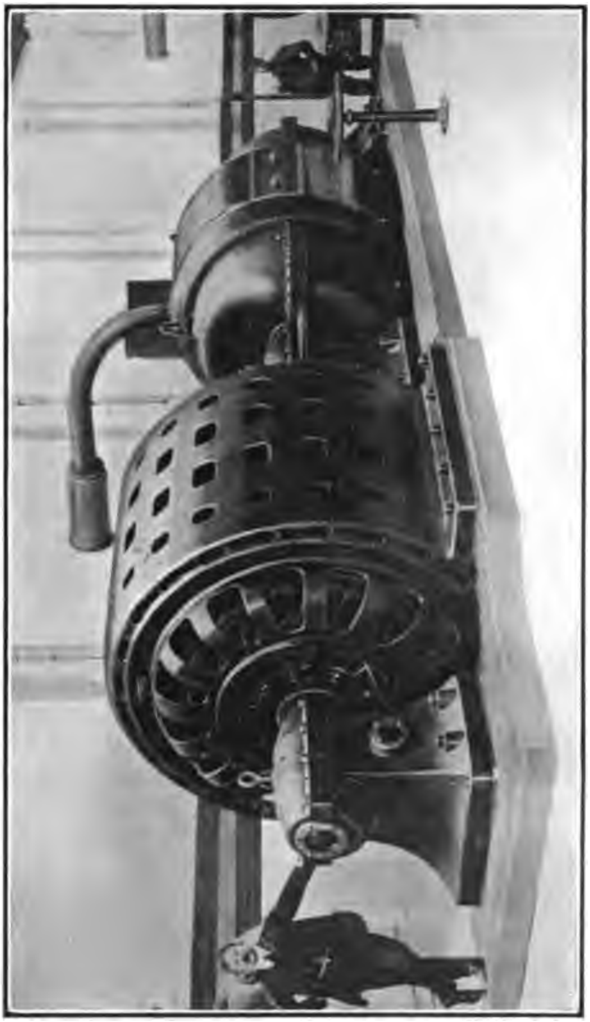

Fig. 82.—Westinghouse-Parsons 2000 K.W. 1500 R.p.m. Set at Yoker, Clyde Valley E. P. Co.

sets supplied by the Westinghouse Co. for the Clyde Valley Power Co.'s station at Yoker.

The Westinghouse Co. are employing the double-flow type as their standard design, only the early machines and the small sizes being of the single-flow type. A section of an early Brush-Parsons turbo-generator is shown in Fig. 84.

The largest turbo-generators probably ever yet undertaken are two 7500 kilowatt units, for which the New York Edison

FIG. 83.—View of Turbine Room, Yoker. (See details, page 528.)

Company has concluded negotiations with the Westinghouse Co., and two 8000 K.W. units of another type (see p. 209).

It is stated that this plant will be installed in one of the largest and most up-to-date American Central Stations—Waterside No. 2—which will ultimately contain ten units of the same size.

The rough overall dimensions are given as—length 15·3 metres, width 5·2 metres, weight 4·6 metres, floor space 7950 square decimetres, or 1·06 square decimetre per kilowatt output.

These figures are published too late to be added in the curves of Figs. 86 to 89, but they have been included in Table XXXVI., where comparison can be made with other sets.

A surface condenser will be located beneath the turbine in the foundations proper. The makers state that this arrangement

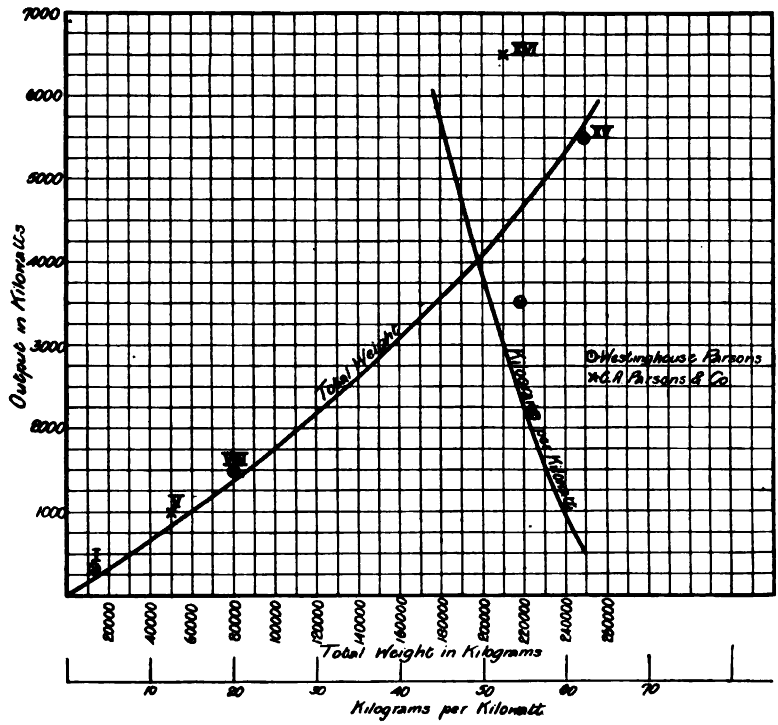

FIG. 86.—Approximate Total Weights of Turbo-Generators of the Parsons Type.

is in all respects equivalent to that claimed as the special property of the vertical type of turbine, which the makers of the latest type state needs considerable extra space for condenser and turbine auxiliaries. The new turbines will operate at approximately 175 lbs. pressure, 28 inch (93·3 per cent.) vacuum, and 100° F. (55·5 C.) superheat, the normal speed being 750 revolutions per minute. Under these conditions the steam consumption is calculated at about 16 lbs. (7·25 kilograms) per kilowatt-hour at full rated load.

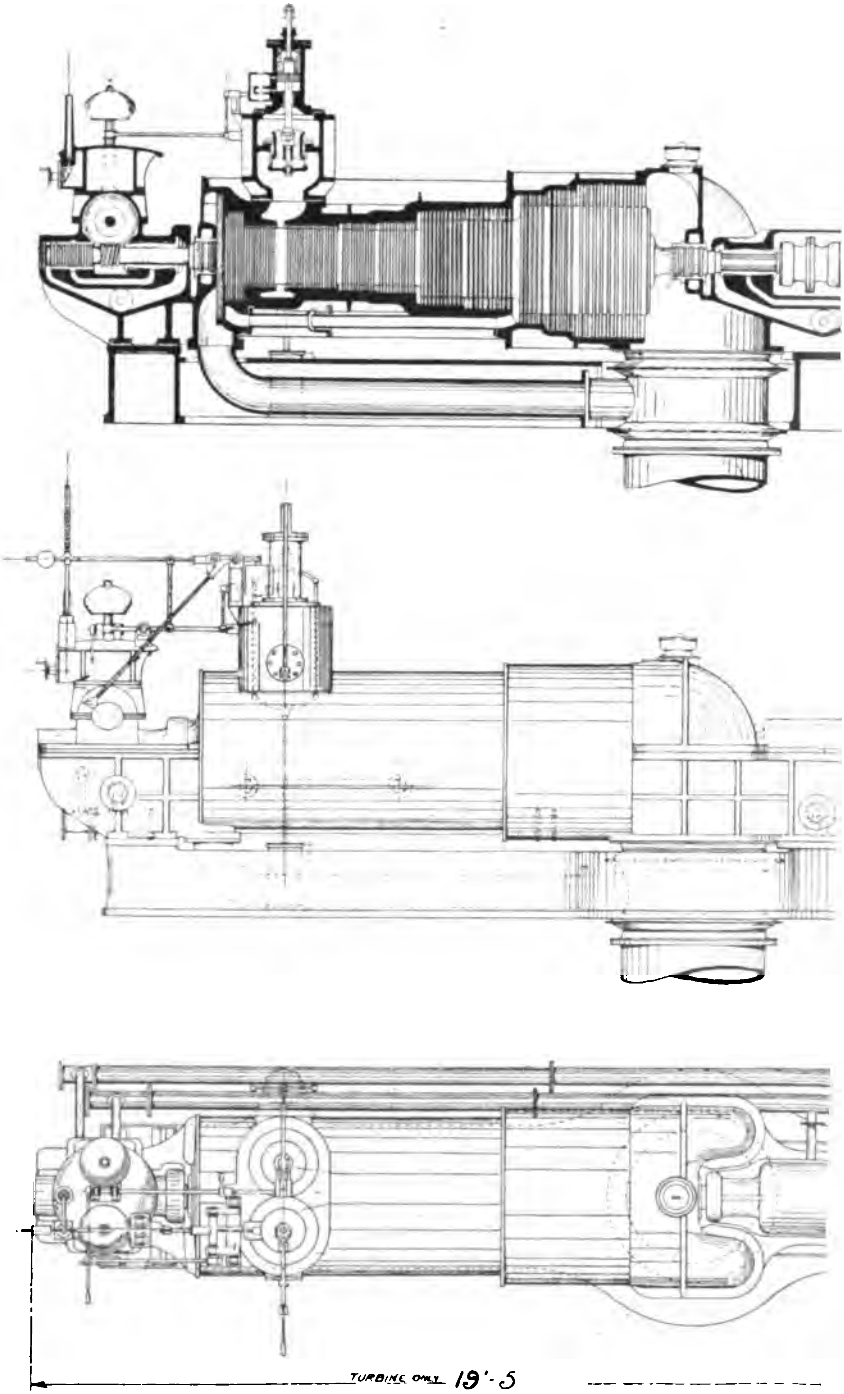

FIG. 84.—1000 K.W. early Brush-Parsons T

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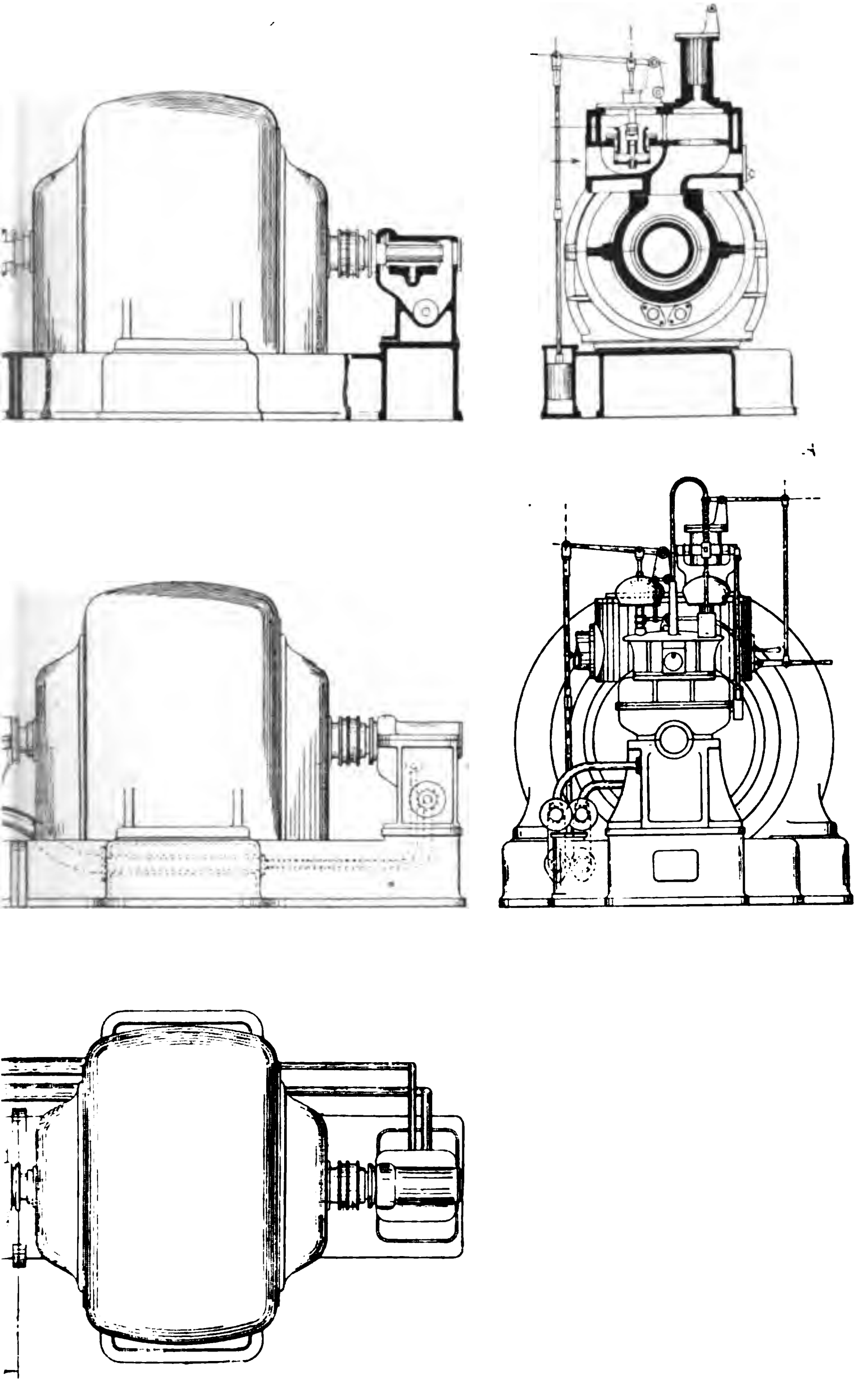
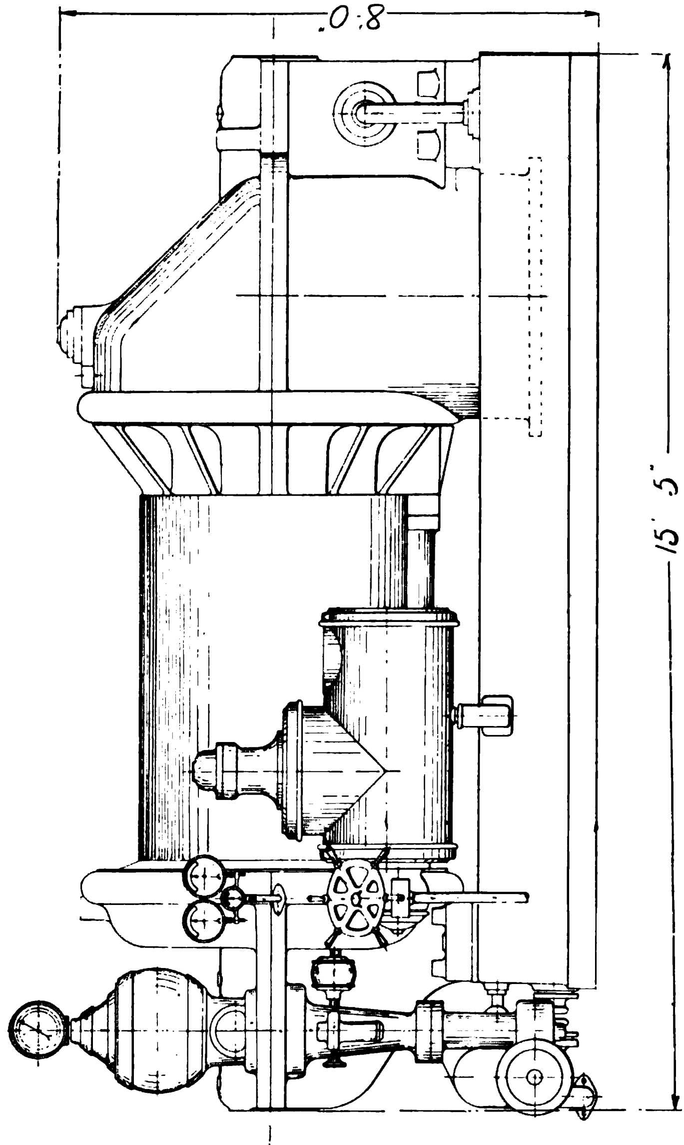


.lternator. **Brush Electrical.Engineering Co.**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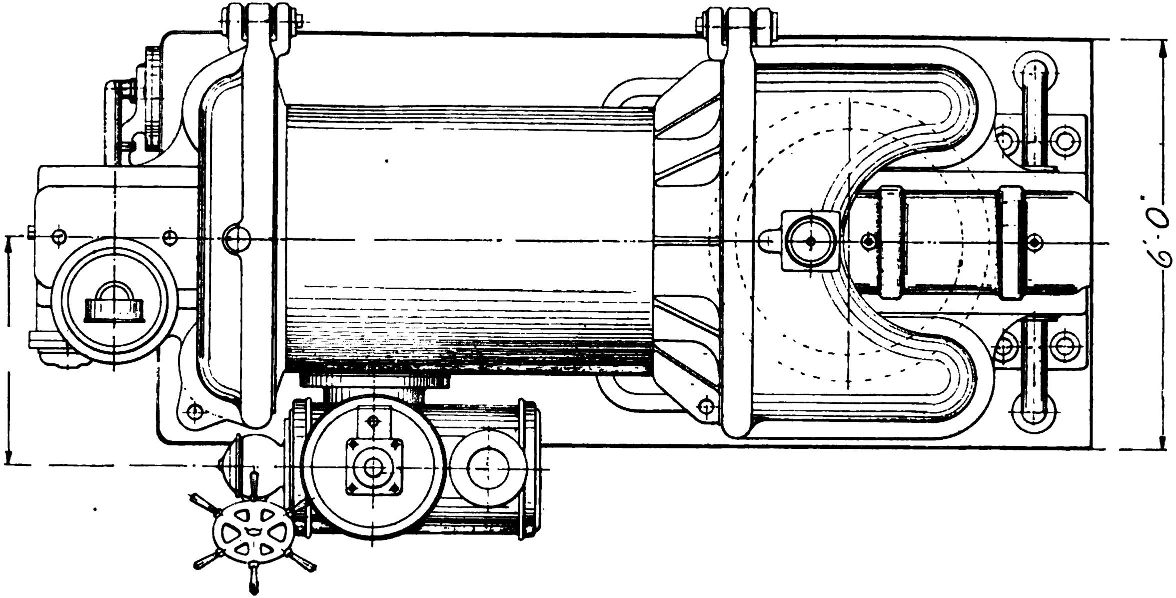


FIG. 85.—1000 K.W. Turbine. Brush Electrical Engineering Co., Ltd.
Latest design.

There will be a maximum overload capacity of 50 per cent. without material sacrifice in efficiency or undue heating of the generator after several hours' run.

At this overload each turbine will develop over 15,000 horse-power at the shaft, which is reckoned as being the greatest amount of power ever developed in a single prime mover in stationary service.

The direct-connected generators will be standard Westing-

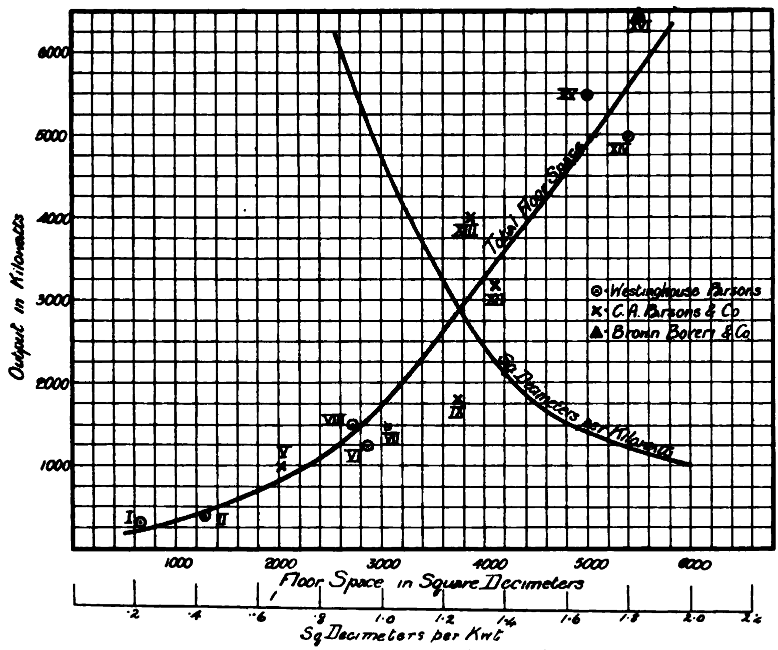


FIG. 87.—Approximate Floor Space occupied by Turbo-Generators of the Parsons Type.

house construction, following the new enclosed design, which is said to eliminate the hum associated with high-speed machines.

They will deliver three-phase current at 6600 volts and 25 cycles.

The efficiency at full rated load approximates to 97·5 per cent.

Messrs Willans & Robinson's design of the Parsons turbine is identical with the Parsons standard type in principle and in its main features, and only in details of design and manufacture are there any differences. To facilitate opening up the turbine for inspection, the governor gear, oil pump, and steam and water piping have been arranged mounted on the bottom half of the

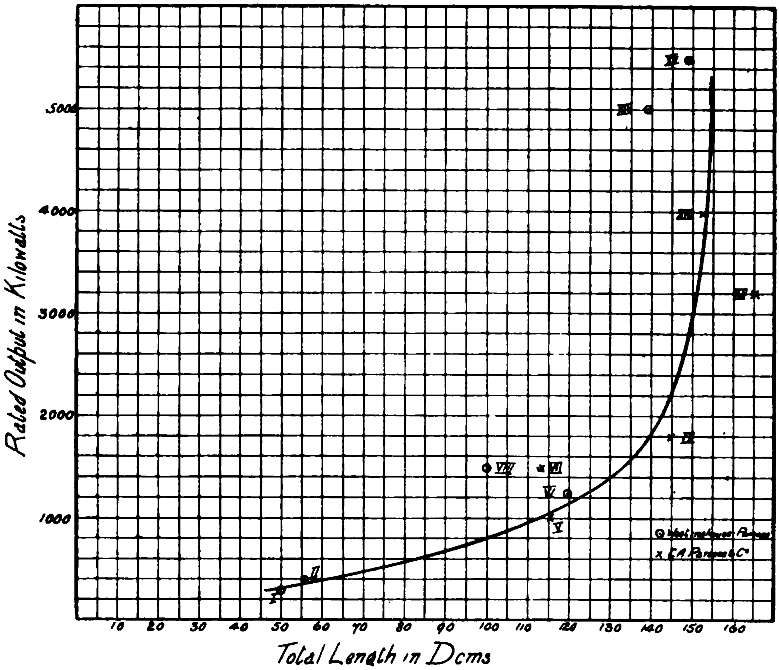


FIG. 88.—Approximate Overall Length of Turbo-Generators of the Parsons Type.

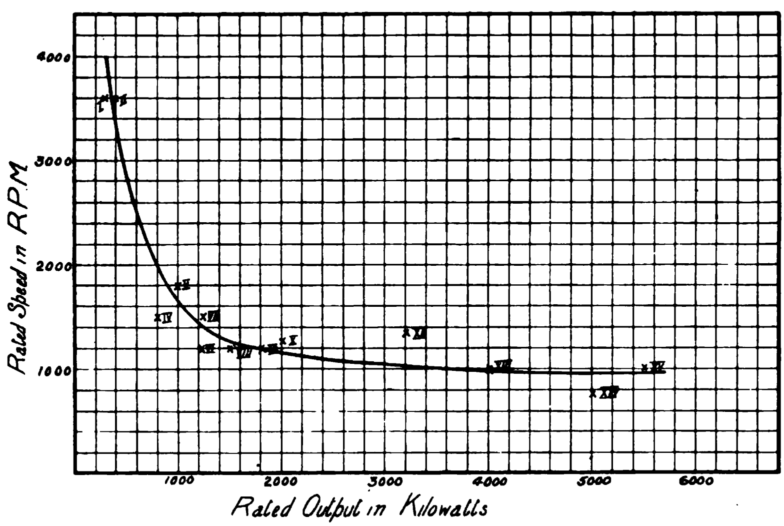


FIG. 89.—Rated Speeds of Turbo-Generators of the Parsons Type.

casing, thus leaving the top half of the case free for immediate removal.

Fig. 90[1] shows a 1000 kilowatt Willans-Parsons turbine opened up. It will be noted that the top cover is hung on hinges whereby it is swung over in a convenient position for inspection.

The governor gear has been simplified and made more reliable, with a view to obtaining good results in the direction of close governing.

All the turbines are fitted with by-pass valves which open automatically when the maximum economical output is exceeded, and by these means any required overload can be obtained.

The length of the turbine has been reduced by a rearrangement of the balancing passages, and for the large balance piston at the high-pressure end has been substituted a considerably smaller one at the low-pressure end.

The vanes are fixed in position by the method under the patent of H. F. Fullagar (No. 21932 (1903)), to which reference has already been made on p. 127.

In the Parsons turbine, efficiency depends on the small clearances between the outer ends of the turbo-vanes and the cylinder casing, and also between the ends of the fixed vanes and the outer periphery of the revolving drum, and such leakage as occurs over the ends of the blades is in a direction contrary to, and tending to destroy, the properly directed stream of steam.

In the Willans construction, for prevention of leakage, reliance is made on the small clearance between the baffling rings and the collars on the rotating drum which hold the fixed vanes, and such leakage as may occur will not be liable to seriously affect the direction of the acting stream of steam.

With high pressure, superheated steam, and a good vacuum, the makers guaranteed a steam consumption not exceeding 17 to 18 lbs. per (7·75 to 8·2 kilogram) kilowatt-hour on a 1000 kilowatt turbine coupled to an alternating current generator.

Fig. 85 represents the Brush Co.'s new type of 1000 kilowatt turbine, which embodies several special features (a sectional drawing of this turbine is given, facing p. 148).

The overall length has been considerably reduced, and in the case of the 1000 kilowatt turbines the overall length is about 1·2 metres (4 feet) shorter than the standard 1000 kilowatt design.

The overall length of turbine and dynamo is about 8 metres

[1] Fig. 90, next page.

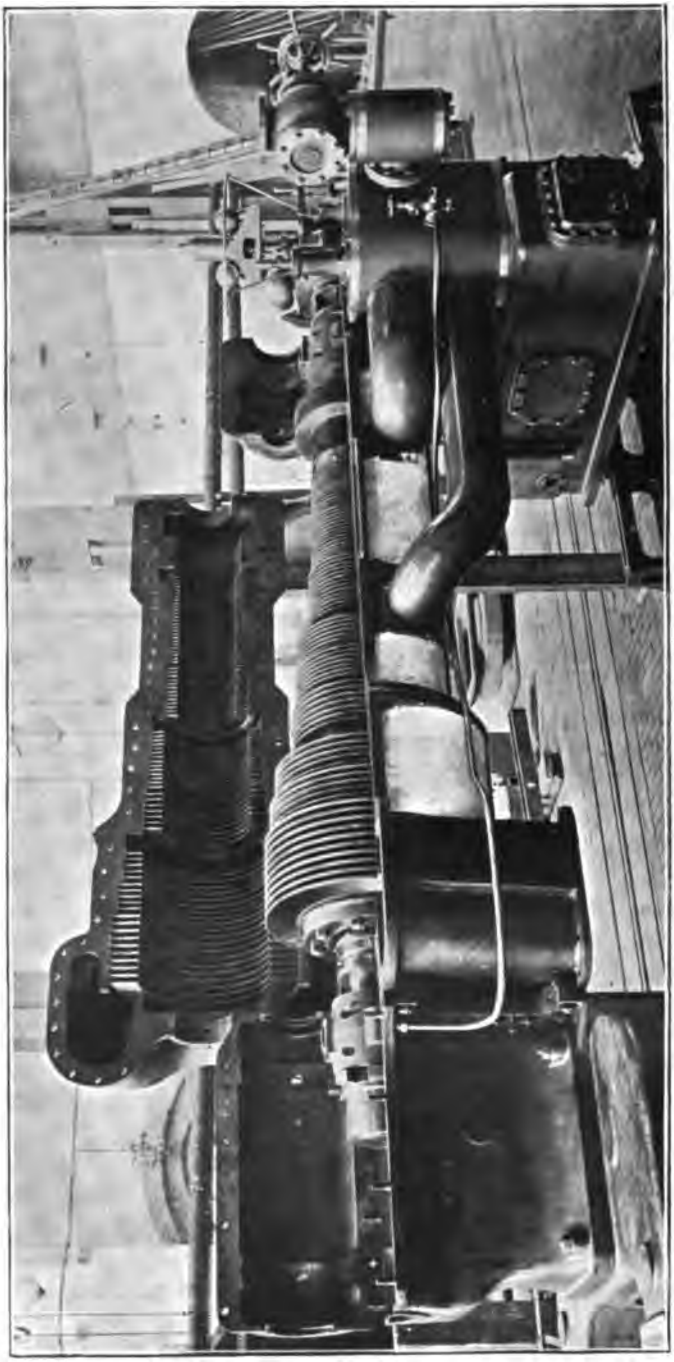


FIG. 90.—View of 1000 K.W. Turbine opened up (Willans-Parsons).

against 11 metres, the mean length for a 1000 kilowatt set, as shown by curve in Fig. 89.

The valve chest is arranged at the side of the bottom half of cylinder, thus allowing the cylinder to be opened out for inspection without breaking any steam-pipe joints, whereas in the Parsons standard types the steam-pipe joints have to be broken, and in the larger sizes the valve chest has to be lifted off as well.

The main bearings are made adjustable both vertically and horizontally, and are also supported on spherical seats.

The oil pump is a rotary one instead of reciprocating, and in the 1500 kilowatt size and above it is driven separately by a motor, and the governor driven direct from the turbine shaft, thus dispensing with worm gear and toothed wheels.

The turbines and generators are carried on one continuous underbed of very stiff box section, which ensures much better alignment of plant when being erected on site.

The oil cooler is contained in this underbed, another portion of which is used as an oil reservoir.

The main lubricating pipes are also contained in the underbed, giving the plant a neater appearance.

Fig. 84 illustrates the original Brush-Parsons 1000 kilowatt turbo-generator, and is shown with the latest type (Fig. 85), whereby some interesting comparisons may be made.

In Table XXXVI. have been compiled some general particulars of a number of representative Parsons turbo-generating sets of various manufacture, and of outputs ranging from 300 kilowatt to 7500 kilowatt.

From the data contained in this table the curves in Figs. 86, 87, 88, and 89 have been plotted.

Fig. 86 shows the weight of complete sets and the weight per kilowatt output, plotted against rated output. In Fig. 87 are plotted total floor space occupied by the complete set, and the floor area per kilowatt output, plotted against output.

Fig. 88 shows the approximate overall length of combined sets, and in Fig. 89 a curve is plotted showing the variation of rated speed of Parsons turbines with the rated output.

The points representing the position of the various machines given in Table XXXVI. are marked on these curves with numbers corresponding to the reference numbers in column 1 of Table XXXVI.

TABLE XXXVI.—SOME PARTICULARS OF DIMENSIONS AND WEIGHTS OF TURBO-GENERATORS OF PARSONS TYPE.

Reference Number.	Rated Output in Kilowatts.	Speed R.p.m.	Rotor Diameter in Metres.	Peripheral Speed in Metres per Second.	Total Number of Fixed and Moving Vanes.	Total Number of Moving Vanes.	Number of Rows of Vanes.	Kilowatts per Moving Vane.	Overall Length of Turbine proper.	Overall Length of Complete Turbo-Generator.	Overall Width of Complete Set.	Floor Space occupied by Complete Set in Sq. Decimetres.	Sq. Decimetres of Floor Space per Kilowatt Output.
I.	300	3600	..	..	..	..	..	..	..	50·0	13·0	650	·46
II.	400	3600	..	..	..	..	116	..	..	56·4	22·8	1285	·31
III.	500	..	..	..	32,000	16,000	..	·031	..	..	..	..	..
IV.	750	1500	·9	70	30,000	15,000	68	·050	..	..	..	..	..
V.	1000	1800	..	..	..	..	..	..	..	115·0	18·0	2070	·44
VI.	1250	1200	..	..	..	..	..	..	..	119·5	23·8	2850	·52
VII.	1500	1000	..	..	..	..	..	..	..	113·0	27·5	3090	·48
VIII.	1500	1200	1·9	120	30,000	15,000	..	·100	58·6	101·0	26·7	2700	·56
IX.	1800	1200	..	..	..	..	..	..	..	145·0	25·9	3760	·48
X.	2000	1260	..	..	..	..	..	..	..	150·0	27·0	4000	·50
XI.	2000	..	..	..	40,000	20,000	..	·100	..	..	..	..	..
XII.	3200	1360	..	..	..	..	..	..	..	165·0	25·0	4125	1·28
XIII.	4000	1000	..	..	..	..	..	..	..	153·0	25·0	3830	·96
XIV.	5000	750	..	..	..	..	..	..	84·4	139·0	40·4	5410	1·08
XV.	5500	1000	1·95[1]	103	..	..	.	..	79·0	147·0	34·5	5500	1·0
XVI.	6500	..	..	..	..	..	..	..	70·0	180·0	30·5	5500	0·85
XVII.	7500	750	..	..	..	..	..	..	..	153·0	52	7950	1·06

[1] Diameter at bottom of vanes = 1·95 m.
" over largest vanes = 2·4 m.

Table XXXVI.—*continued.*

Reference Number.	Approximate Total Weight of Complete Set in Kilograms.	Kilograms of Total Weight per Kilowatt Output.	Date installed.	Type of Generator coupled to Turbine. A.C. Alternating C. C.C. Continuous C.	Place where Plant is installed.	Manufacturers of the Turbines and Generators.
I.	11,350	38	..	A.C.	Westinghouse Air Brake Works, U.S.A.	Westinghouse-Parsons.
II.	..	..	1904	A.C.	St Louis Exposition.	Westinghouse-Parsons.
III.	..	..	..	..	..	Westinghouse-Parsons.
IV.	..	..	.	..	..	..
V.	50,000	50	1902	C.C.	Newcastle and District Elec. Light. Co.	C. A. Parsons & Co.
VI.	..	..	..	A.C.	..	Westinghouse-Parsons.
VII.	..	..	1903	A.C.	Sheffield.	C. A. Parsons & Co.
VIII.	80,000	57	..	A.C.	Hartford Elec. Light. Co., U.S.A.	Westinghouse-Parsons.
IX.	..	..	1902	C.C.	Manchester.	C. A. Parsons & Co.
X.	..	..	1902	A.C.	Milan.	C. A. Parsons & Co.
XI.	..	..	1904	A.C.	Clyde Valley Elec. Power Co., Yoker.	Westinghouse-Parsons.
XII.	..	..	1902	A.C.	Frankfort-on-Main.	Parsons Turbine and Brown-Boveri. Gen.
XIII.	..	27·5	1903	A.C.	..	Parsons Turbine and Brown-Boveri Gen.
XIV.	..	..	..	A.C.	Manhattan Railways.	Westinghouse-Parsons.
XV.	250,000	24	1904	A.C.	Underground Railways of London.	Westinghouse-Parsons.
XVI.	200,000	26	1905	A.C. & C.C.	Essen.	Brown, Boveri & Co.
XVII.	..	..	Under construction.	A.C.	New York Edison Co.	Westinghouse-Parsons.

We purpose now to consider the question of steam consumption of the Parsons steam turbine. The results of a very large number of careful tests are available, and these have been brought together in Table XXXVII. As in the case of the corresponding discussion of the de Laval sets, we have assumed a hypothetical direct-connected dynamo in those cases where no dynamo was present, and we have suitably modified the results by means of the dynamo efficiency curves in Figs. 16 to 19 (see pp. 38 and 39 of Chapter III.) so as to express the steam consumption in terms of the kilograms of steam per kilowatt-hour output from this hypothetical dynamo. In cases where the tests were originally made with a direct-connected dynamo, no reference to the efficiency curves of Figs. 16 to 19 has been necessary.

The most striking point revealed by an analysis of the tests set forth in Table XXXVII. is, that the steam consumption is practically independent of the admission pressure for a very wide range of pressures. We were, of course, aware that the admission pressure made far less difference than in the case of reciprocating steam engines. We find, however, that for a vacuum of 86·6 per cent. and for 50° Cent. of superheat, of two turbines of a given rated capacity, but designed, say, the one for an absolute admission pressure of 7 metric atmospheres, and the other for 14 metric atmospheres, the steam consumption is, on the average, generally just about the same. It may be of interest to describe the rough but practical methods of analysis by which we have arrived at this result.

Individual tests on a particular turbine at different pressures naturally give results showing a slight variation with the pressure, but our general conclusion, as summed up above, is based upon the average of a large collection of tests, and may fairly be taken as corresponding to turbines suitably designed for the pressures with which they are to be used.

In Figs. 91 to 98 are plotted the results of tests on turbines of the same rating at each of two or three different pressures in each case.

In all these figures the curve A corresponds to the lower pressure, curve B to the higher; and in cases where test figures were available for a still higher pressure, curve C is drawn corresponding thereto. Out of all the numerous test figures available, in only one case can we find results for one and the same turbine tested at two different pressures on various loads. These results relate to a 3200 kilowatt Brown-Boveri-Parsons

TABLE

20 per c Load.

Ad … … 11·0 7·5 …

Degrees Cent. Superheat at Admission.	Date of Test.	Place of Test.	Test Conducted by.	Manufacturer of the Turbine.		
…	…	…	…	Parsons	"Trials of Steam Engineers' Con	11·9
…	…	…	. .	Do.	Do.	11·6
…	…	…	…	Do.	"The Steam Turb *Elec. Engrs.*, v	11·6 …
42·3	…	…	…	Do.	"Trials of Steam " Engineers' Con	11·6
32·7	…	…	…	Do.	Do.	9·8
0	…	…	…	Do.	"Trials of Steam T Engineers' Con	11·6 11·6
6·0	…	…	…	Brown-Boveri Co.	Messrs Brown, Bo	11·6
51·0	…	…	…	Parsons	"The Steam Turb *Elec. Engrs.*, v	1·6
2·8	. .	…	…	Do.	"Trials of Steam " Engineers' Con	0·15
..	…	…	…	Do.	"The Steam Turb *Elec. Engrs.*, v	…
…	…	…	..	Brown-Boveri Co.	Messrs Brown, Bo	…
0	…	…	…	Parsons	"The Steam Turb *Elec. Engrs.*, v	0·0
0	…	…	…	Brown-Boveri Co.	Messrs Brown, Bo	1·6
9·0	…	…	…	Parsons	"The Steam Turb *Elec. Engrs.*, v	1·6
…	…	…	…	Do.	Do.	1·6
…	…	…	…	Brown-Boveri Co.	Messrs Brown, Bo	1·6
..	…	…	…	Do.	Do.	1·6
0·51	…	…	…	Parsons	"The Steam Turb *Elec. Engrs.*,	1·6
2·0	…	…	…	Do.	Do.	1·6
65	…	…	…	Brown-Boveri Co.	Messrs Brown, Bo	1·6

turbo-generator, and are taken from the *Electrotechnische Zeitschrift*, Heft 35, p. 749 (August 24th, 1904).

The tests were made at pressures of 10 and 14 kilograms per

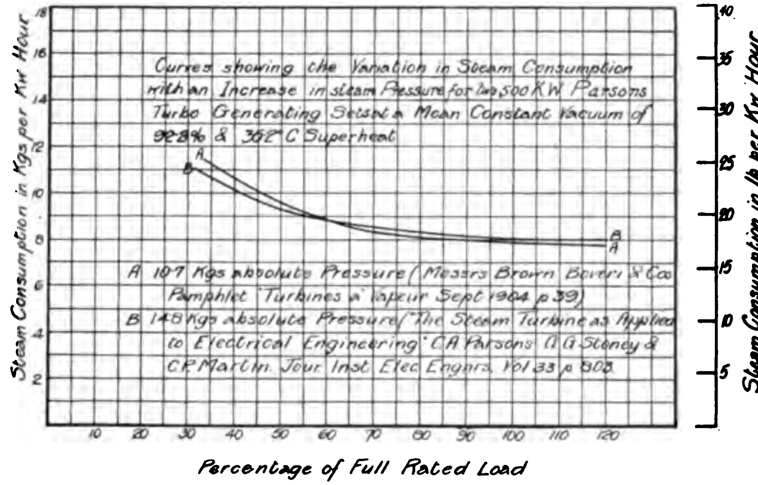


FIG. 91.—500 K.W. Parsons.

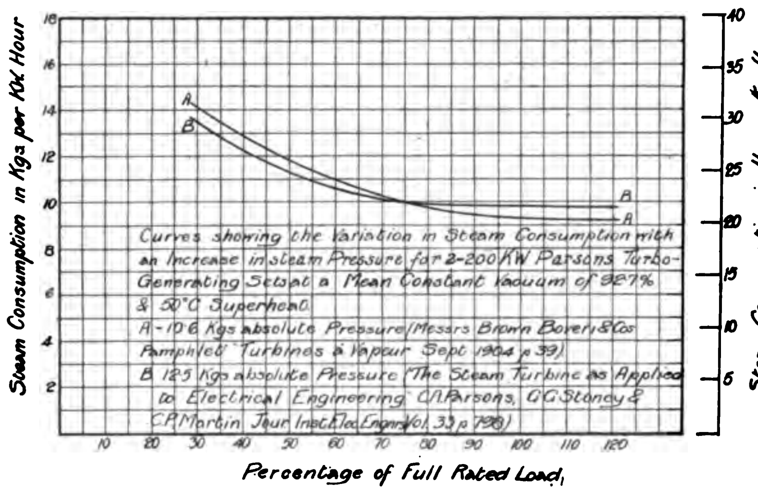


FIG. 92.—200 K.W. Parsons.

FIGS. 91 and 92.—Variation in Steam Consumption with Change in Pressure.

square centimetre, and the results are plotted in Fig. 98. From the curve we see that for this machine the steam consumption at full load decreased from 6·86 kilograms to 6·5 kilograms for an increase in admission pressure from 10 kilograms per square centi-

metre to 14 kilograms per square centimetre; that is, a 40 per cent. increase in pressure gave a decrease of 5·2 per cent. in steam

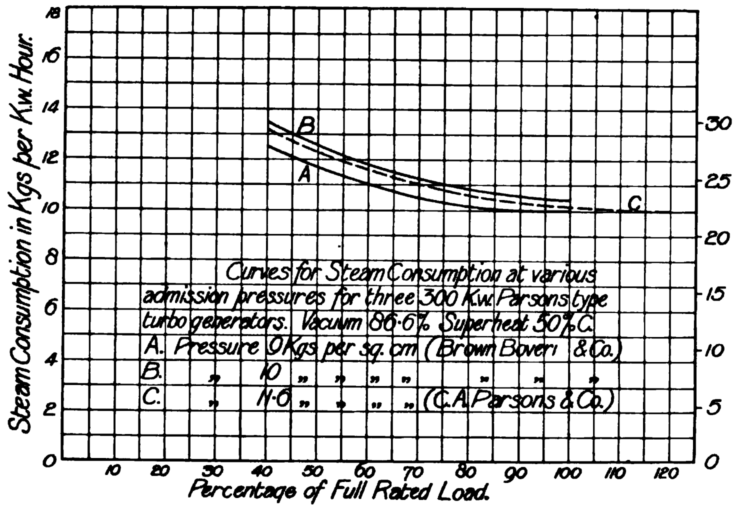


FIG. 93.—300 K.W. No. VIII. on Tables XXXVI. and XLII.

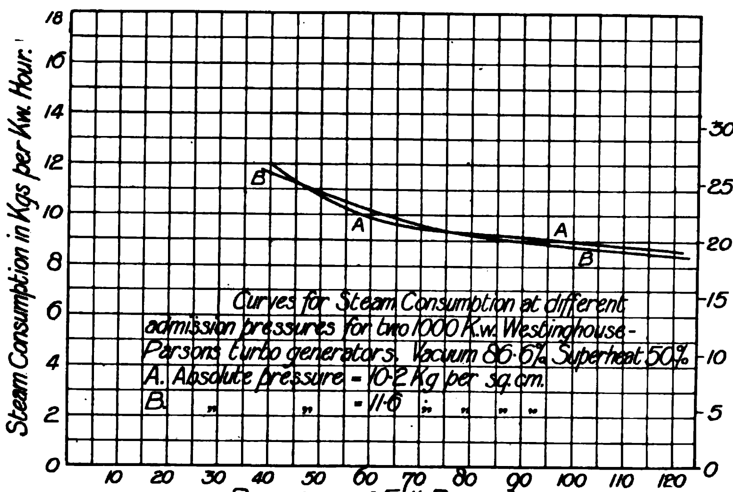


FIG. 94.—1000 K.W. No. XIV. on Tables XXXVII. and XLII.

FIGS. 93 and 94.—Variation in Steam Consumption with Change in Pressure.

consumption; the decrease in steam consumption for each per cent. increase in pressure thus being 0·13 per cent. at full load.

The two curves cross at about 42 per cent. of full load, the

Reference.
›ines for Driving Dynamos," C. A. Parsons and G. G. Stoney, Paper read before the International ;, Glasgow, 1901, Sec. III. (mechanical), and arranged by the Inst. of Mech. Engrs., pp. 11 to 13.
do. do. p. 16.
rs. Journ., vol. xv. p. 1252, November 1903.
e Theoretical and Practical Considerations in Steam Turbine Work," *Trans. Amer. Soc. of Mech.* Table of Test Results).
e Remarks on Steam Turbine Performances," *Trans. of the Inter. Elec. Cong., St Louis*, 1904, 93.
& Co.'s Pamphlet *Turbines à Vapeur*, September 1904, p. 39.
ɔ Theoretical and Practical Considerations in Steam Turbine Work," *Trans. Amer. Soc. of Mech.* y 1904, p. 32.
do. p. 32.
do. p. 32.
do. p. 32.
do. p. 30.
; Applied to Electrical Engineering," C. A. Parsons, G. G. Stoney, and C. P. Martin, *Jour. Inst.* 3, p. 803, May 12, 1904.
do. p. 804.
: Co.'s Pamphlet *Turbines à Vapeur*, September 1904, p. 39.
1, p. 93.
1, p. 93, March 1904, p. 93.
p. 94.
Theoretical and Practical Considerations in Steam Turbine Work," *Trans. Amer. Soc. of Elec.* · 1904 (see Table of Test Results).
Applied to Electrical Engineering," C. A. Parsons, G. G. Stoney, and C. P. Martin, *Jour. Inst.* , p. 799, May 12, 1904.
: Co.'s Pamphlet *Turbines à Vapeur*, September 1904, p. 39.
do. do. p. 39.
Heft 34, p. 749, August 25, 1904.
do.
do.
9, 1905, vol. 56, p. 943. Apparently Makers' Guarantees,—these are not Test Results.
do. do.

...
...
8·3
9·8

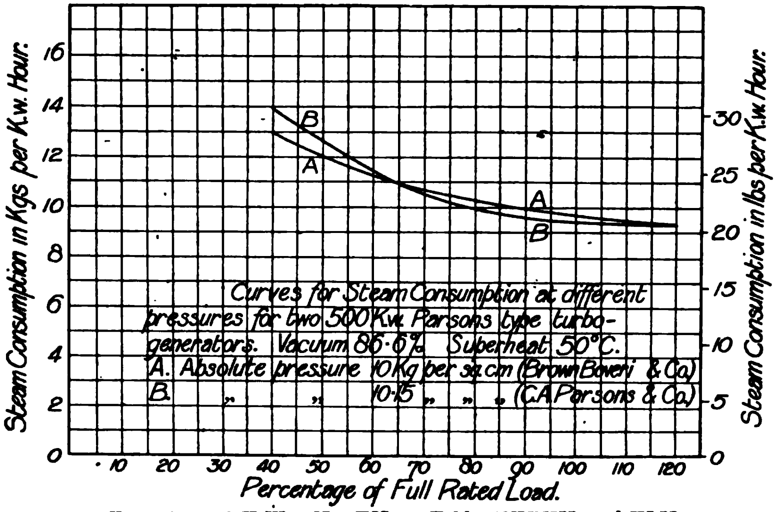


FIG. 95.—500 K.W. No. XII. on Tables XXXVII. and XLII.

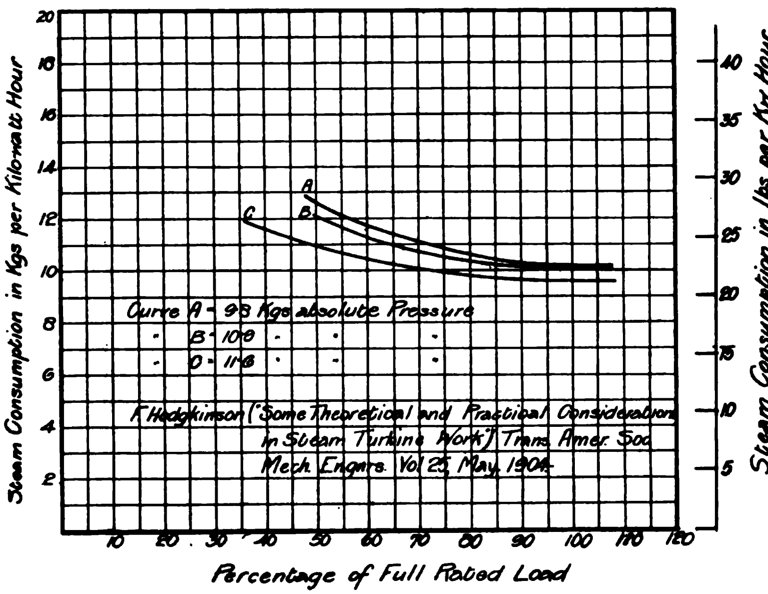


FIG. 96.—400 K.W. Westinghouse 86·6 per cent. Vacuum, no Superheat. Tests Nos. 1–10 in Table.

FIGS. 95 and 96.—Variation in Steam Consumption with Change in Pressure.

steam consumption at this load being the same for the two different admission pressures. For loads less than this, the steam consumption is actually greater for the higher pressure.

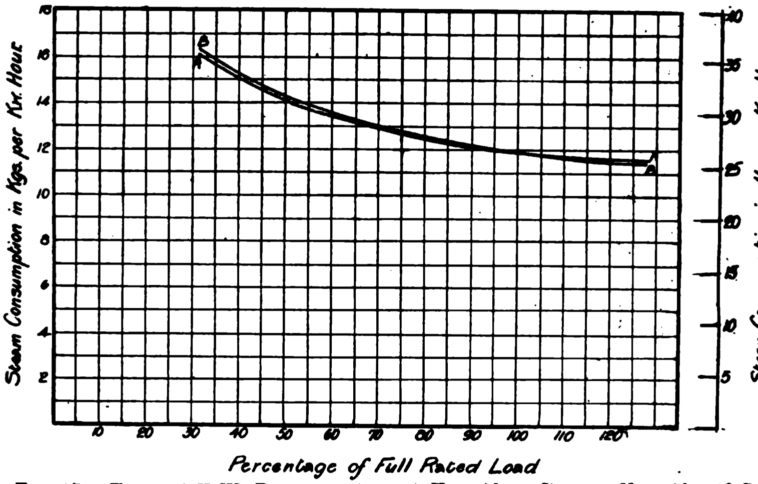


FIG. 97.—Two 100 K.W. Parsons. A.—8·7 Kgs. Abs. B.—9·9 Kgs. Abs. 8° C. Superheat, 90·5 per cent. Vacuum.

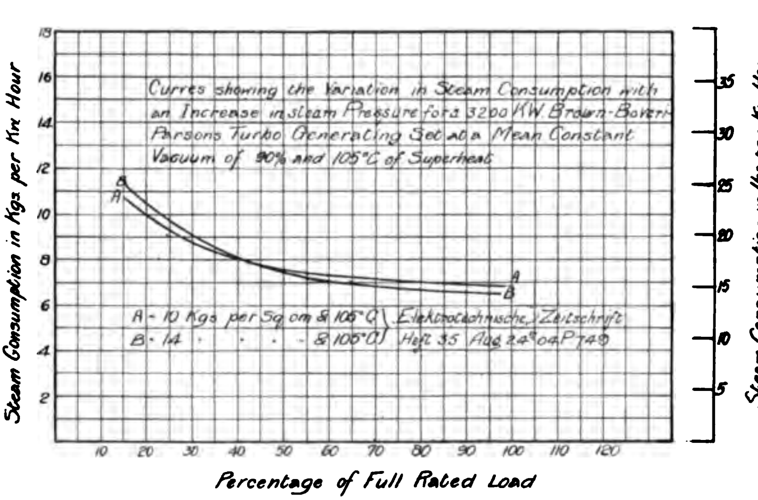


FIG. 98.—3200 K.W. Brown-Boveri-Parsons set.

FIGS. 97 and 98.—Variation in Steam Consumption with Change in Pressure.

A.—Messrs Brown, Boveri & Co., *Turbines à Vapeur*, Sept. 1904, p. 39.
B.—"Trials of Turbines for Driving Dynamos," by C. A. Parsons and G. G. Stoney, International Engineering Congress, Glasgow, 1901.

This is probably explained by the loss due to leakage of steam being greater the higher the pressure of the steam, and to the increased friction due to rotation in a denser medium.

In each of the other Figs., 91 to 97, we have brought

together turbines of the same rating to compare their steam consumption at different pressures, but under the same conditions as to vacuum and superheat.

In three of these cases, Figs. 91, 92, 93, the steam consumption is actually higher for the higher pressure at full load.

This result is contrary to experience, and we would attribute it to the fact that in each case the tests at different pressures were made on two separate turbines, when slight differences in construction and workmanship might account for either machine being inferior to the other as regards steam economy.

In the four cases of Figs. 94 to 97 the results are similar to that in Fig. 98 referred to above—viz. at light loads the steam consumption is greater for higher pressures, and at loads from about one-half load and upwards the consumption is smaller for higher pressures, there being a certain load where the consumption is apparently the same for all pressures.

In the case of Fig. 94 the two curves actually cross in two places; and, bearing in mind that each curve is for a different machine, we would regard this as evidence of the differences in steam consumption being due rather to differences in the characteristics of the machines than to the effect of difference in pressure.

We have not thought it sufficiently justifiable to attempt to determine the law of variation of steam economy with pressure on the basis of these results to any degree of accuracy, but results of tests on individual turbines with varying pressure for each, at several conditions of load, would be very desirable for this purpose.

We also obtained from various manufacturers of the Parsons type of steam turbine statements indicating that in their experience the variation of steam consumption with varying admission pressure has been found to be very small at all loads, although they all find a slowly improving economy accompanying increasing admission pressure.

With non-condensing sets the use of a high pressure undoubtedly has a marked effect in improving the economy, but we consider it sufficiently well established by our investigations that for turbines of the Parsons type, as at present designed and built, when operated with a good vacuum, the improvement in economy from an absolute admission pressure of 8 kilograms per square centimetre upwards is so slight as to not be worth taking into account.

At any rate, it is extremely unlikely that an improvement in

steam economy of more than about 0·10 per cent. per per cent. increase in admission pressure will be obtained at full load under good conditions as to vacuum and superheat for an absolute admission pressure of 7 kilograms per square centimetre; and this will probably decrease to an improvement of not more than 0·05 per cent. per per cent. increase in admission pressure for absolute admission pressure of some 14 kilograms per square centimetre. For the range of pressures customarily employed (10 to 16 absolute atmospheres) the steam consumption at full load can thus, for all practical purposes, be taken as independent of the admission pressure.

It is somewhat premature to announce this conclusion prior to the description of the following exhaustive analysis of published data of steam comsumption.

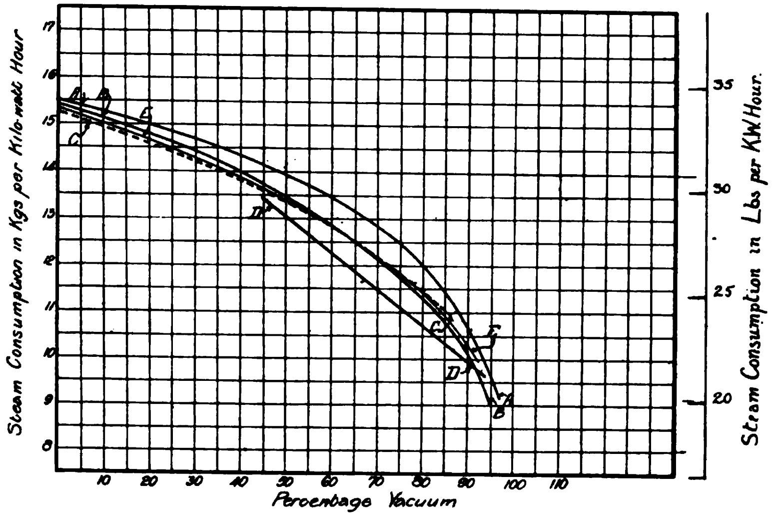
For a preliminary assumption, we proceeded to ignore the influence of variations in the admission pressure, and to investigate the laws of variation with vacuum and superheat.

The effect of varying vacuum has been studied by a number of investigators. The results on five different turbines at full rated load are shown in Fig. 99. Representing by 100 the steam consumption at 86·6 per cent. vacuum, the results of Fig. 99 have been reproduced in Fig. 100, and it appears that the tests are in close agreement as regards the percentage variation in full load steam consumption with varying vacuum, as to be represented by a single curve. In other words, the same rate of variation may, for all practical purposes, be taken for all sizes of Parsons turbines.

From Fig. 100 we see that a Parsons turbine consumes at full load 38 per cent. more steam when running non-condensing than when running with a vacuum of 86·6 per cent. Of course, there may be considerable variations from this particular percentage in individual cases, as the development of the Parsons turbine has extended over many years, and the principles of design have been gradually developed during this time.

Furthermore, in all analyses of this character the difficulty arises that a turbine is designed for some particular pressure, vacuum, or amount of superheat, and hence it is argued that comparative tests, when one of these conditions is varied, do not afford correct information as to the relative economy of turbines designed for the different conditions. While this is to some extent true, the conclusions drawn from a single turbine operated under varied conditions may nevertheless often afford a fairly good idea of the influence of such variations, even when a special design is provided

for each case. Thus there have been published by Barker (*Engineering*, Feb. 19th, 1904, p. 270) the two curves shown in Fig.



Curve	Rated Output in Kilowatts.	Absolute Pressure in Kgs.	Superheat in Degs. Cent.	Type of Turbine.	Source of Data.
A	500	10·9	0	Parsons	"Trials of Steam Turbines for Driving Dynamos," C. A. Parsons and G. G. Stoney, before the International Engineering Congress, Glasgow, 1901, Section III., Inst. of Mech. Engrs.
B	300	11·6	0	Westinghouse-Parsons	"The Economics of High Vacua and Superheat in Steam Turbine Plants," J. R. Bibbins, p. 175, *Report American Street Railway Assoc.*, St Louis, 1904.
C	500	11·3	0	Parsons	"The Steam Turbine as applied to Electrical Engineering," C. A. Parsons, G. G. Stoney, and C. P. Martin, *Jour. Inst. Elec. Engrs.*, vol. 33, p. 801.
D	360	11·1	44·5 changed to 0	Parsons	p. 802.
E	300	12·1	0	Parsons	p. 800.

FIG. 99.—Steam Consumption with Varying Vacuum.
Average Pressure 11·4 *Kgs. per Sq. Cm. and no Superheat.*

101. These show the variation in economy with varying vacuum for the case of two turbines, one (curve A) designed to run non-condensing, and the other (curve B) designed to run con-

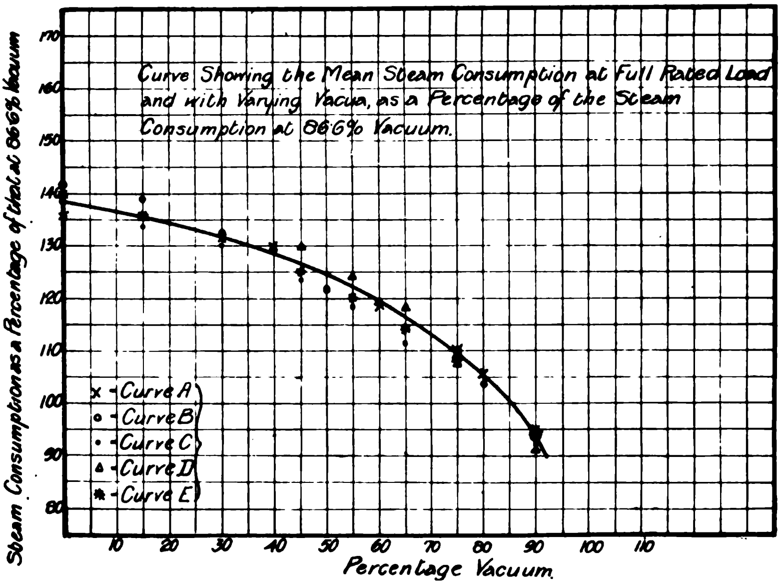


FIG. 100.—Mean Steam Consumption at Full Load for Parsons Turbines with Varying Vacua. See Curves A to E, Fig. 99.

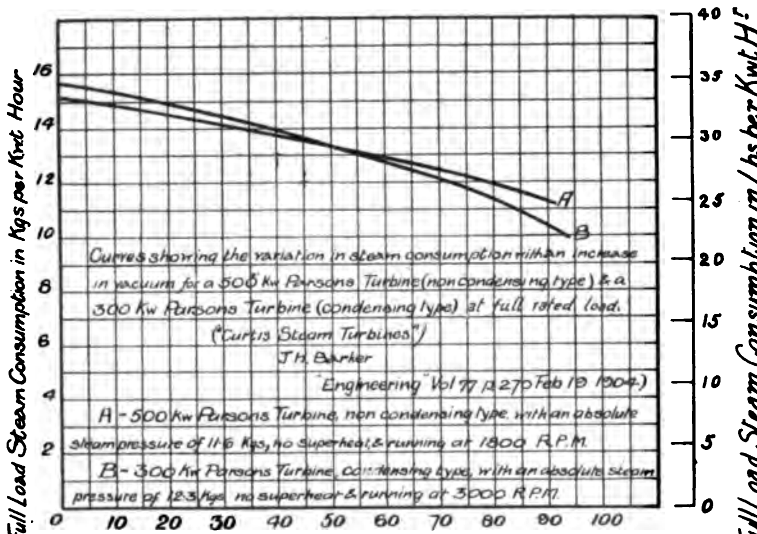


FIG. 101.—500 K.W. and 300 K.W. Parsons Turbines with Varying Vacua.

densing. The curves fall very close together, and the conclusions drawn from either curve would, for the practical man, give the

required information for either case with sufficient accuracy. Both curves were taken at full rated load.

It is next necessary to investigate the effect of varying vacuum at other than full rated load. Fig. 102 contains results republished by Messrs Parsons and Stoney. They relate to tests of a 500 kilowatt set at quarter, half, and full load, and at varying vacua. The corresponding curves in Fig. 103 have been deduced

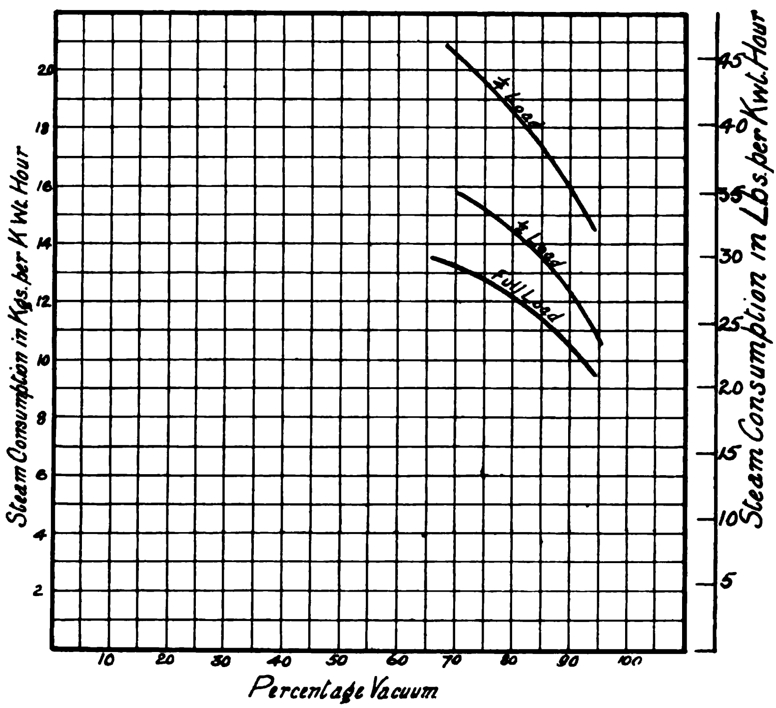


FIG. 102.—Steam Consumption with an Increase in Vacuum for a 500 K.W. 2500 R.p.m. Parsons Turbo-Alternator, *Abs. Steam Pressure* 10·85 *Kgs. and no Superheat.* ("Trials of Steam Turbines for Driving Dynamos," C. A. Parsons and G. G. Stoney, International Engineering Congress, Glasgow, 1901, Table VII.)

by representing the steam consumption at 86·6 per cent. vacuum by 100 in each case. From the relative positions of the three curves of Fig. 103, it is evident that the percentage decrease in steam consumption is, for a given increase in vacuum, greater the less the load.

In Figs. 104 and 105 are given corresponding results obtained by Bibbins on a 300 kilowatt turbine.

It is assumed that the percentage improvement in economy

with increasing vacuum is independent of the degree of superheat. There is as yet an insufficiency of published data to permit us to verify this assumption.

Neither the tests of Parsons and Stoney (Figs. 102 and 103) nor those of Bibbins (Figs. 104 and 105) are as clear as they

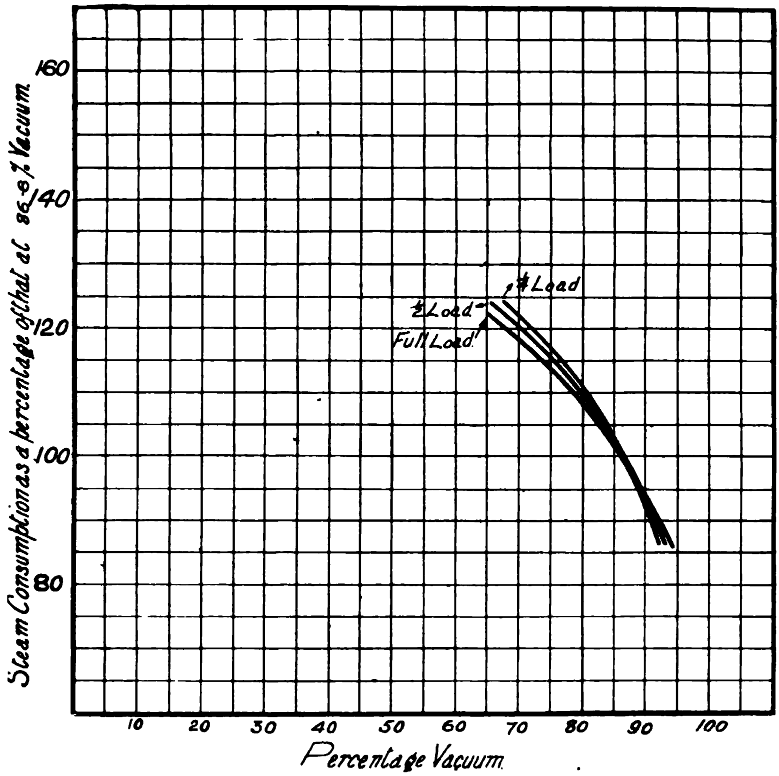


FIG. 103.—Percentage Variation in Steam Consumption with an Increase in Vacuum. A 500 K.W. 2500 R.p.m. Parsons Turbo-Alternator at Various Loads, with a Constant Absolute Steam Pressure of 10·85 Kgs. and no Superheat.

might have been made by these authors. This will appear from the following considerations:—

In Fig. 106 is given a curve of the steam consumption of a 500 kilowatt turbine set at no load, with varying vacuum, absolute pressure of 10·9 metric atmospheres, and no superheat. This is plotted from Table 8 of Parsons and Stoney's paper, and, extended as shown by the dotted line, indicates that the steam consumption when running non-condensing would be 2900 kilograms per hour, or 3·10 times as great as for an 86·6 per cent. vacuum. In this

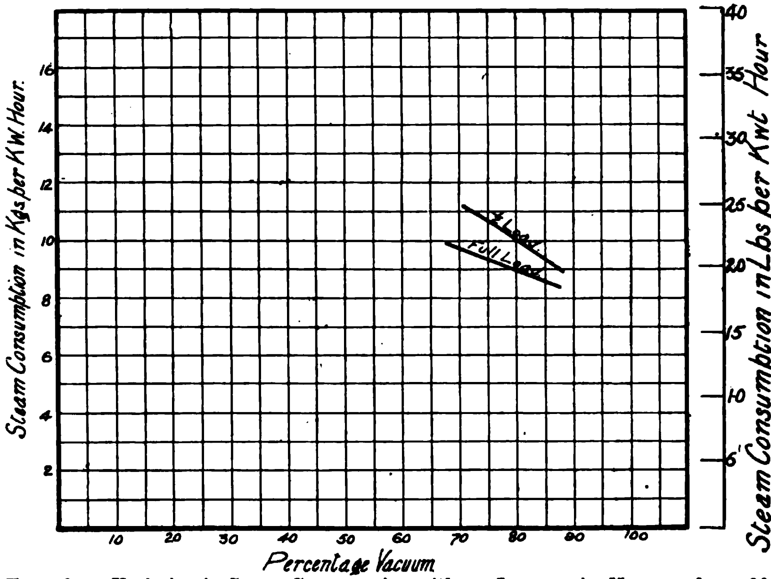


Fig. 104.—Variation in Steam Consumption with an Increase in Vacuum for a 300 K.W. Westinghouse-Parsons Turbine, 11 Kgs. per Sq. Cm. Abs. and no Superheat. (*Steam Turbine Power Plants*, J. R. Bibbins, *American Street Railway Association*, *St Louis*, 1904.)

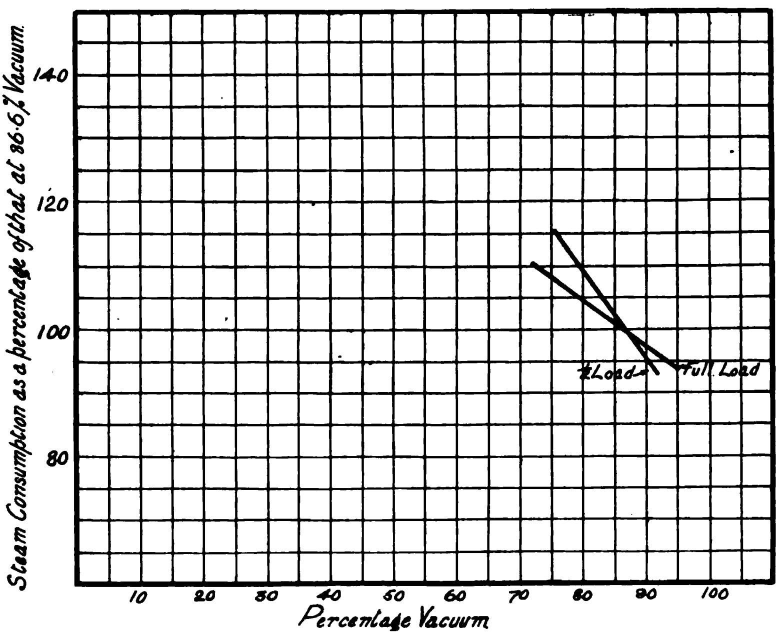


Fig. 105.—Percentage Variation in Steam Consumption derived from Fig. 104, *q.v.*

same paper of Parsons and Stoney is found the following statement:—

"In non-condensing plants also many tests have been made, but, as will be expected, the steam turbine compares rather more favourably with the reciprocating engine in condensing types. In a 100 kilowatt size a consumption of 39 pounds per kilowatt-hour has been attained, and in a 250 kilowatt turbo-dynamo 38 pounds per kilowatt-hour, both with about 130 pounds steam pressure and no superheat. In larger sizes of 1500 kilowatt with 200 pounds

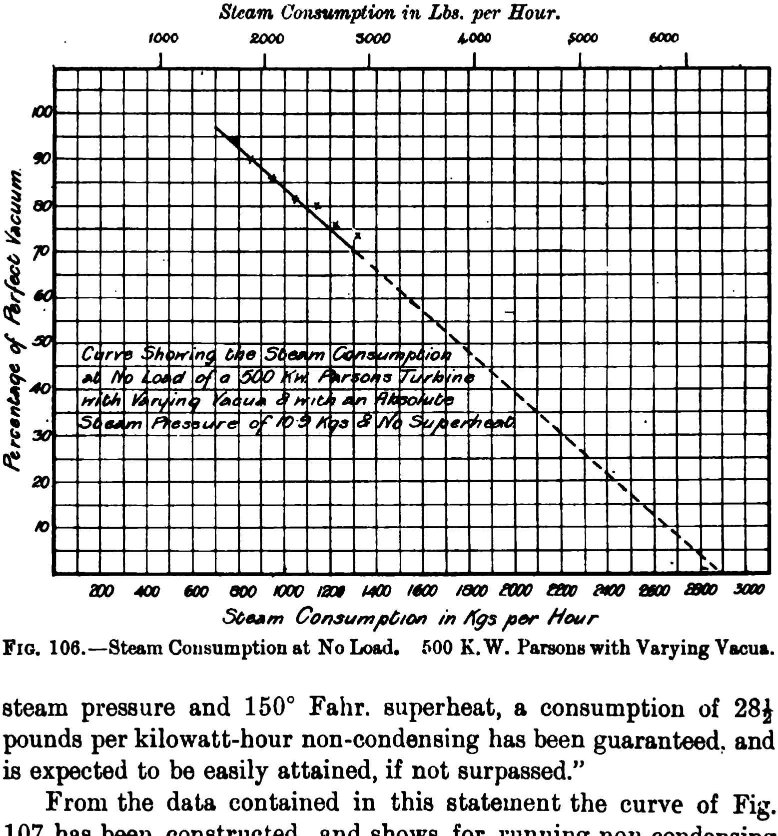


FIG. 106.—Steam Consumption at No Load. 500 K.W. Parsons with Varying Vacua.

steam pressure and 150° Fahr. superheat, a consumption of $28\frac{1}{2}$ pounds per kilowatt-hour non-condensing has been guaranteed, and is expected to be easily attained, if not surpassed."

From the data contained in this statement the curve of Fig. 107 has been constructed, and shows for running non-condensing with no superheat a full load steam consumption of 16·5 kilograms per kilowatt-hour for a 500 kilowatt set.

We now have sufficient data of the 500 kilowatt set to work out the graphical construction shown in Fig. 108.

We obtain the full load point for other than an 86·6 per cent. vacuum by applying percentage corrections obtained from the curve

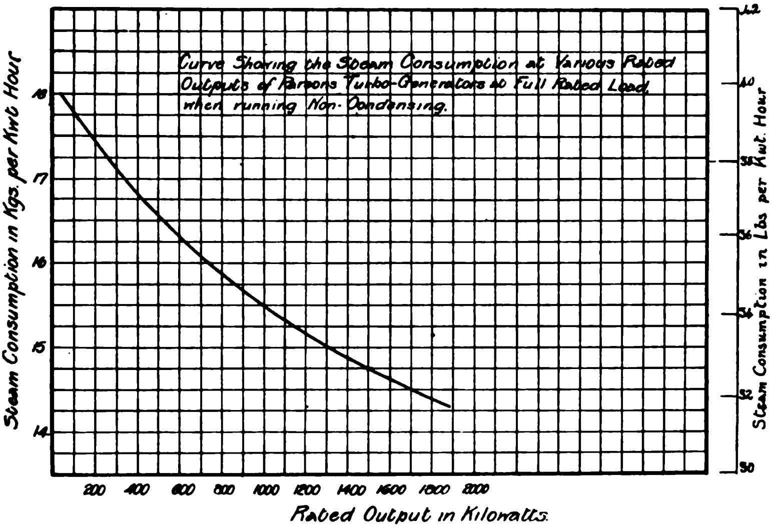


FIG. 107.—Steam Consumptions at Full Load Non-condensing Parsons—50 K.W. to 1900 K.W.

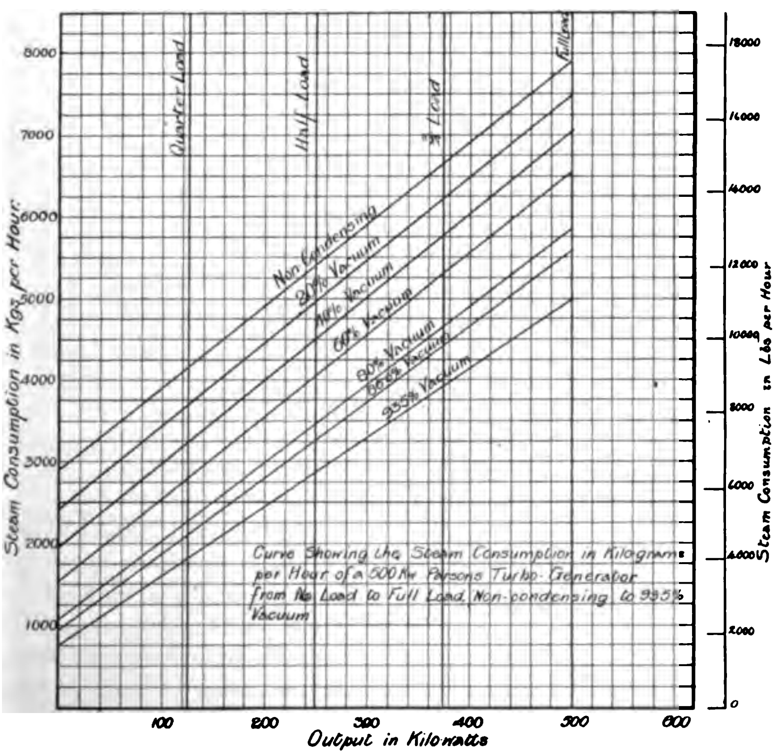


FIG. 108.—Steam Consumption 500 K.W. Parsons set for different Vacua and all Loads.

of Fig. 101. The steam consumptions at no load for different vacua are obtained from Fig. 106. We then draw straight lines connecting these two points, and can thus obtain the steam consumptions at intermediate loads by interpolation. In the curves of Fig. 108 we obtain the steam consumption in kilograms per hour, but from these values are readily deduced the steam consumptions expressed in kilograms per kilowatt-hour as shown in Fig. 109.

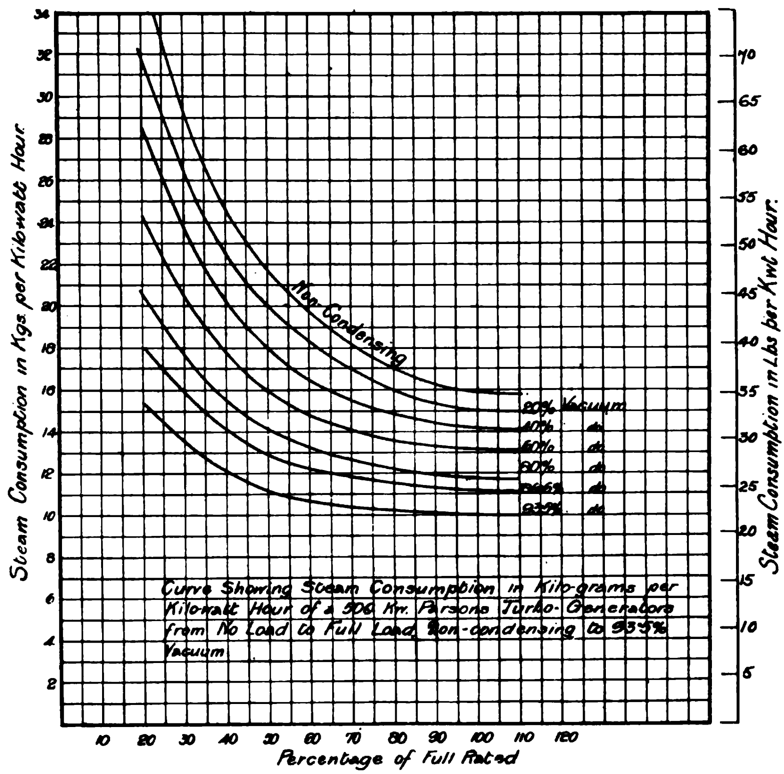


FIG. 109.—Steam per K.W.H. 500 K.W. Parsons Turbine.

Guided by the conclusions embodied in the curves in Figs. 100 and 109, we have obtained the curves in Fig. 110, which show for Parsons turbines at full rated load, half load, and quarter load the percentage decrease in steam consumption per per cent. increase in vacuum. Thus, by increasing the vacuum from 83·4 per cent. (25 inches) to 86·6 per cent. (26 inches), mean vacuum = 85·0 per cent. (25·5 inches), we obtain the results shown in Table XXXVIII.

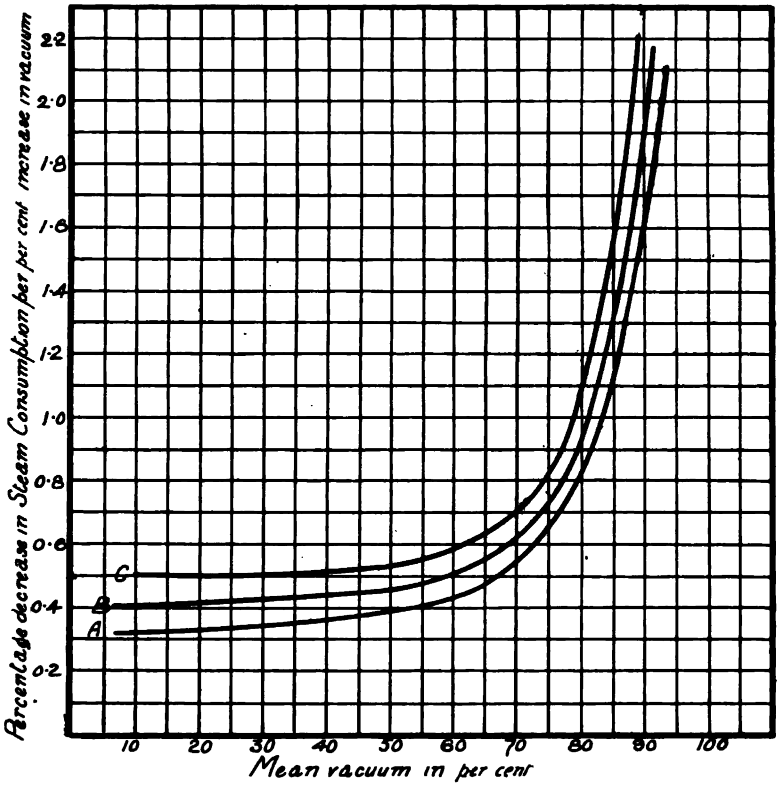


FIG. 110.—Percentage Variation in Steam Consumption with Changes in Vacua, Parsons Turbo-Generators.
A—Full Load; B—Half Load; C—Quarter Load.

TABLE XXXVIII.

	Quarter Load.	Half Load.	Full Load.
Percentage decrease in steam consumption per per cent. increase in vacuum for a mean vacuum of 85 per cent. (25·5 in.)	1·6 per cent.	1·3 per cent.	1·1 per cent.
Percentage decrease in steam consumption obtained by increasing the vacuum from 83·4 per cent. (25 in.) to 86·6 per cent. (26 in.), *i.e.* by a total increase of 3·3 per cent. (or of 1 in.)	5·3 per cent.	4·3 per cent.	3·6 per cent.

An equal absolute increment in vacuum (*i.e.* 1 inch) from 86·6 per cent. (26 inches) upwards, *i.e.* to 90 per cent. (27 inches),

gives a considerably greater percentage improvement in economy, as shown in Table XXXIX.

TABLE XXXIX.

	Quarter Load.	Half Load.	Full Load.
Percentage decrease in steam consumption per per cent. increase in vacuum for a mean vacuum of 88·3 per cent. (26·5 in.)	2·0 per cent.	1·6 per cent.	1·4 per cent.
Percentage decrease in steam consumption obtained by increasing the vacuum from 86·6 per cent. (26 in.) to 90 per cent. (27 in.), *i.e.* by a total increase of 3·3 per cent. (or of 1 in.)	6·6 per cent.	5·3 per cent.	4·6 per cent.

The results in Tables XXXVIII. and XXXIX. are brought together in Table XL., as also results for higher vacua.

TABLE XL.

	Quarter Load.	Half Load.	Full Load.
Percentage decrease in steam consumption obtained by increasing the vacuum by 1 in. from—			
25 in. to 26 in. (83·4 per cent. to 86·6 per cent)	5·3 per cent.	4·3 per cent.	3·6 per cent.
26 in. to 27 in. (86·7 per cent. to 90 per cent.)	6·6 per cent.	5·3 per cent.	4·6 per cent.
27 in. to 28 in. (90 per cent. to 93·3 per cent.)	8·6 per cent.	7·3 per cent.	6·0 per cent.

Vacua above 28 inches are, in the present state of steam condenser engineering, not generally economical propositions, owing to the great first cost and running expenses of the condensing equipment.

We are now in a position to eliminate variations in vacuum used in the different tests (Table XXXVII.), and to reduce the steam consumption results to a standard vacuum of 86·6 per cent. (26 inches).

Superheat.—The next variable relates to the dependence of the steam consumption upon the degree of superheat. In Figs. 111 to 115 are plotted curves taken on several sizes of turbines with varying degrees of superheat. For these curves the abscissæ

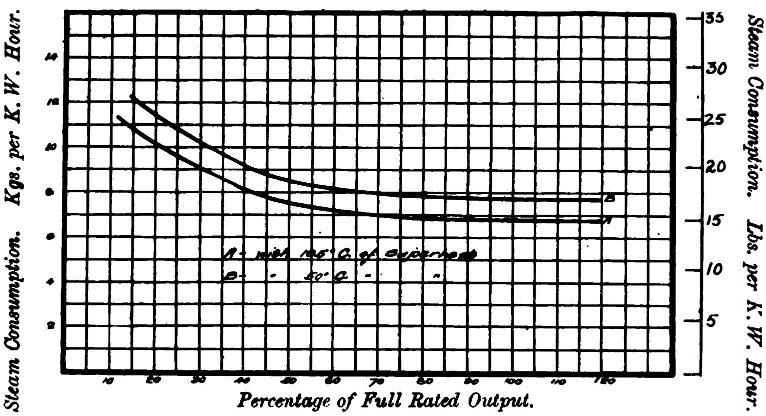


FIG. 111.—3200 K.W. Brown-Boveri-Parsons Turbo-Generator, Constant Pressure 10 Kgs. Abs. and Constant Vacuum 90 per cent., *Electrotechn. Zeits.*, H. 34, p. 749, Aug. 25, 1904.

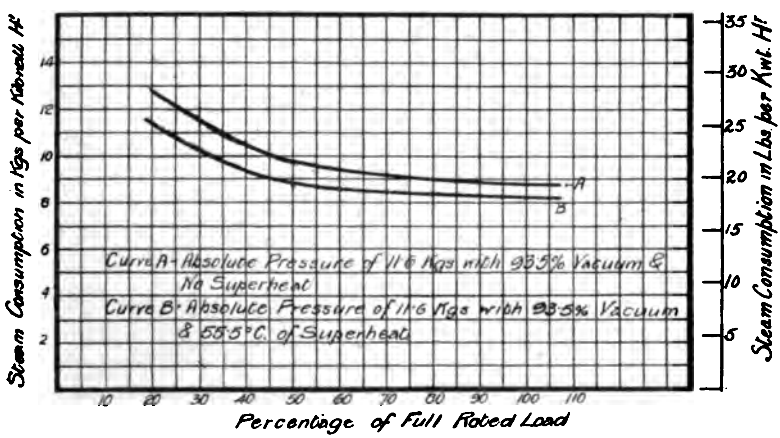
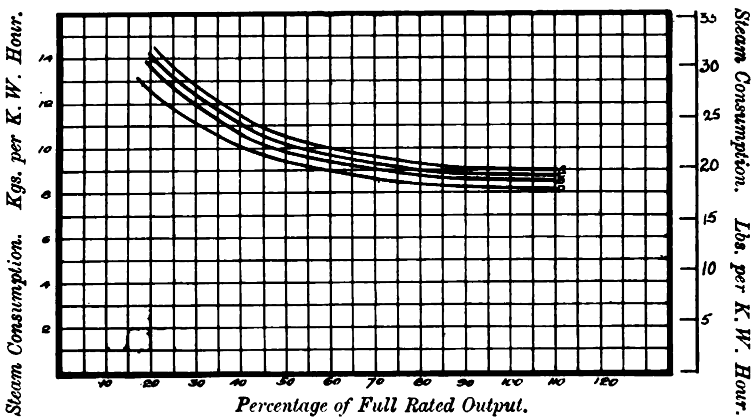


FIG. 112.—1250 K.W. Westinghouse-Parsons Turbine.
(F. Hodgkinson, *Trans. Amer. Soc. of Mech. Engrs.*, vol. xxv., May 1904.)

FIGS. 111 and 112.—Variations in Steam Consumption with Varying Superheat.



A = 11·4 Kgs. Abs. 90 per cent. Vacuum and no Superheat.
B = ,, ,, 90·5 per cent. Vacuum and 42° C. Superheat.
C = ,, ,, 94 per cent. Vacuum and no Superheat.
D = 11·5 ,, 94 per cent. Vacuum and 43° C. Superheat.

FIG. 113.—1250 K.W. Westinghouse-Parsons Turbo-Generator.
(F. Hodgkinson, *Trans. Amer. Soc. of Mech. Engrs.*, vol. xxv., May 1904.)

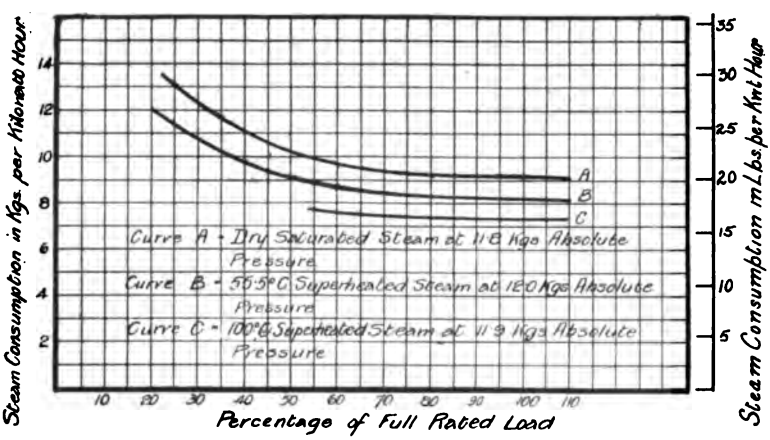


FIG. 114.—400 K.W. Westinghouse-Parsons Turbo-Generator,
Constant Vacuum 93·5 per cent.
(F. Hodgkinson, *Trans. Amer. Soc. of Mech. Engrs.*, vol. xxv., May 1904.)

FIGS. 113 and 114 —Variations in Steam Consumption with Varying Superheat.

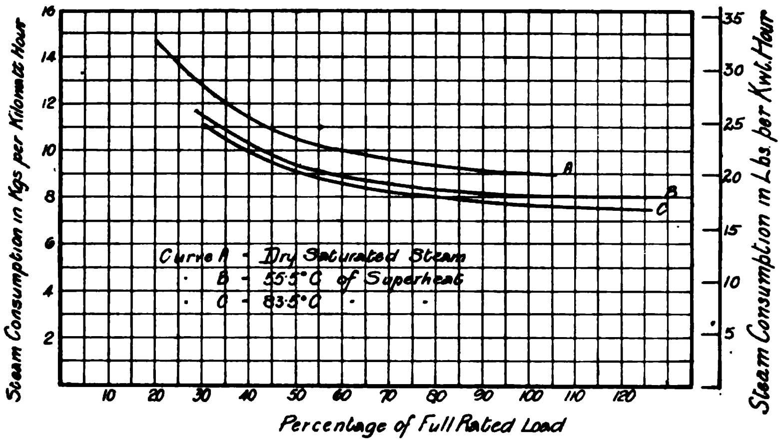
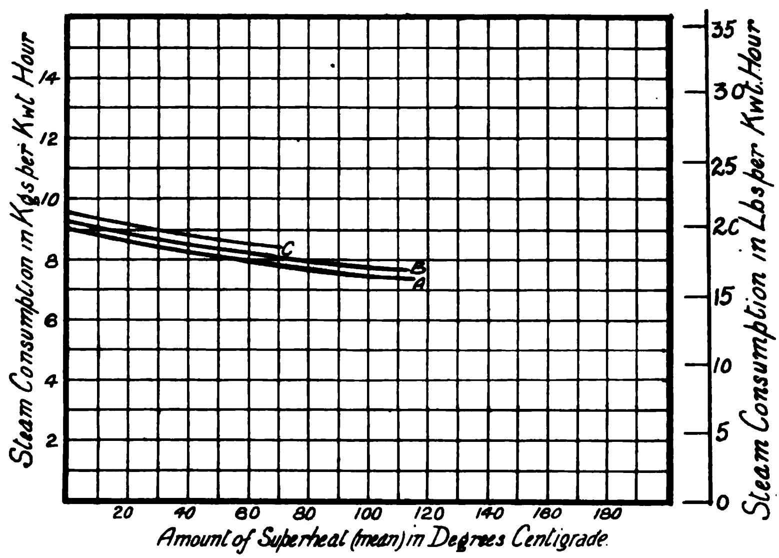


FIG. 115.—Variations in Steam Consumption with Varying Superheat,—750 K.W. Parsons Turbine.
Constant Pressure of 11·6 Kgs. Abs. and 93·5 per cent. Vacuum.



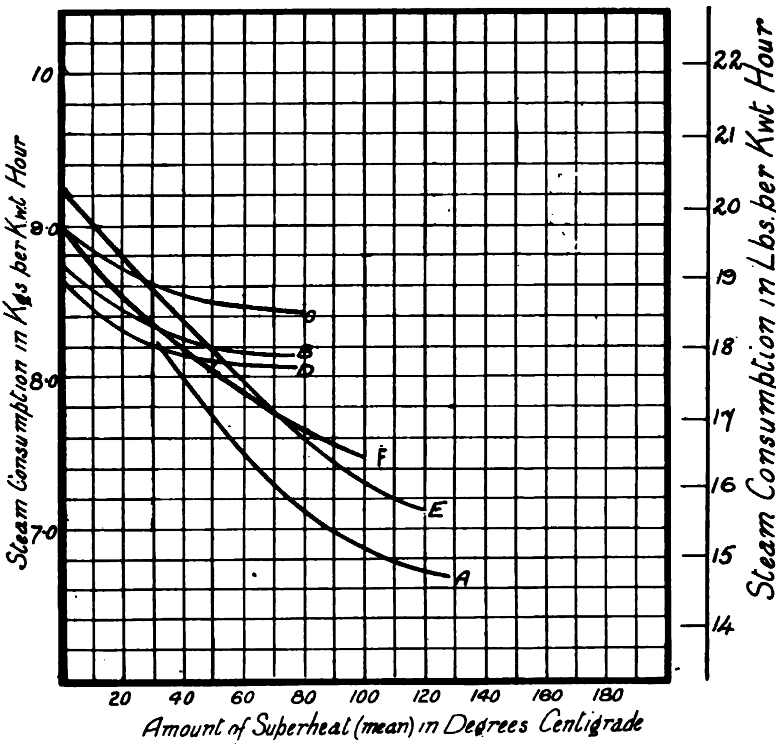
A = 126–132 per cent. of Full Rated Load.
B = 102 ,, ,,
C = 77 ,, ,,

FIG. 116.—The Variation in Steam Consumption for an Increase in Superheat at Stated Loads for a 400 K.W. Westinghouse-Parsons Turbine, at a Constant Vacuum of 93·5 per cent. and a Mean Absolute Steam Pressure of 11·9 Kgs. ("Brake Tests," *Engineering*, p. 559, Oct 21, 1904.)

denote the percentage of rated full load. For the curves of Fig. 116 the abscissæ denote the degrees of superheat, it having been

more convenient in the case of these tests, which were made at definite percentages of rated load, to plot the results in this way.

The values of the steam consumption at rated full load have for all these cases been employed in plotting the curves of Fig. 117,



A = See Fig. 111.		D = See Fig. 113.	
B = ,,	112.	E = ,,	114.
C = ,,	113.	F = ,,	115.

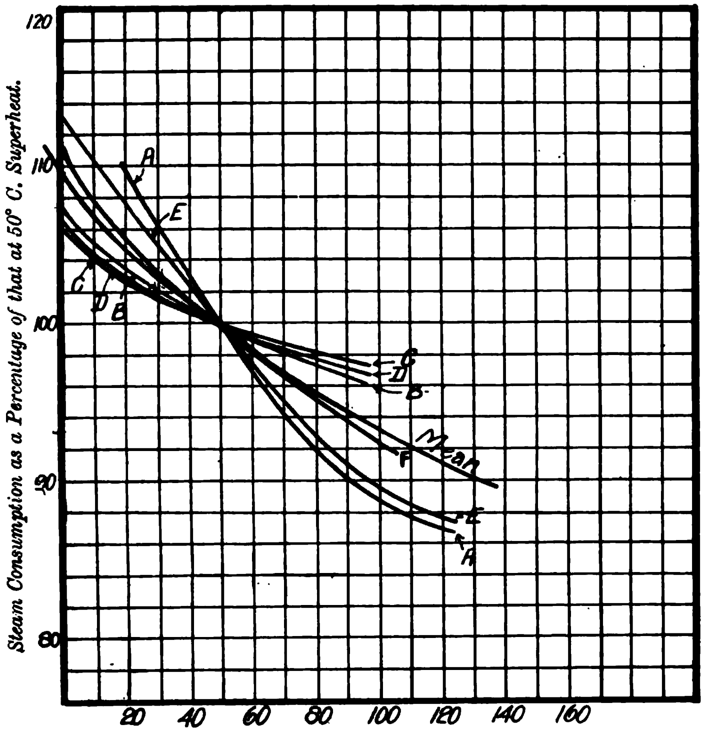
FIG. 117.—The Steam Consumption of Various Sizes of Parsons Steam Turbine at Full Rated Load with Varying Superheat.

in which superheats in degrees Centigrade are employed as abscissæ.

Fig. 118 is derived from the curves of Fig. 117 by representing by 100 the steam consumption with 50° Cent. of superheat. The mean curve drawn for this group is reproduced in Fig. 119, and may be taken as a fairly true indicator, for the Parsons type of turbine, of the amount by which the degree of superheat affects the steam economy at rated full load.

But at light loads the effect of a given amount of superheat is to improve the steam economy to a somewhat greater extent than at full load. This is evident from a study of Table XLI.

An analysis of the above table shows us that a given amount of superheat in degrees Cent. occasions a percentage improvement in steam economy at 20 per cent. of full load, which may be



Superheat in Degrees Centigrade. Letters refer to Fig. 117.

FIG. 118.—Variations in Full Load Steam Consumption with Varying Superheat of a Parsons Turbine.

roughly taken as some 25 per cent. greater than the corresponding percentage improvement at rated full load. The value varies greatly, however, and appears (see curves of Fig. 113, corresponding to 90 per cent. and 94 per cent. vacua) to be also dependent upon the accompanying vacuum. There is, however, insufficient data for tracing out the extent of the dependence upon the vacua of the improvement in economy with increasing superheat, and it will not be taken into further consideration. The three

curves in Fig. 120 relate respectively to quarter, half, and full rated load.

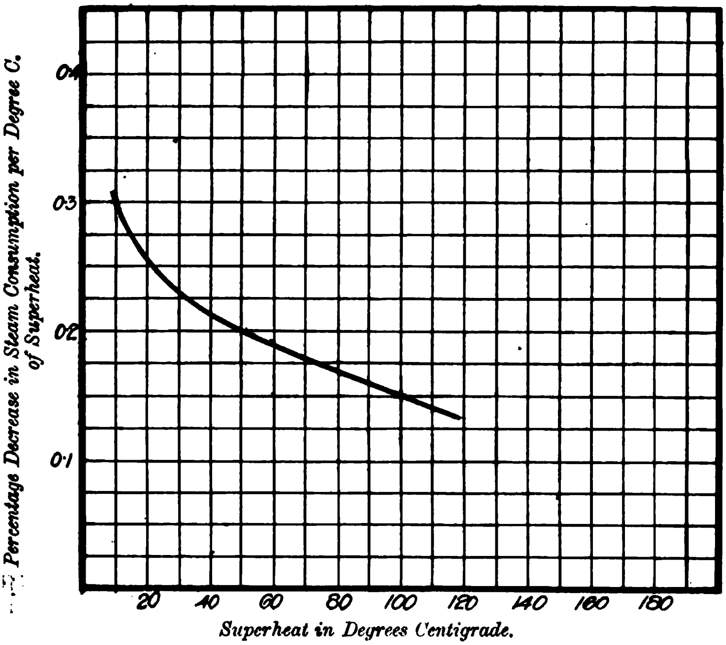


FIG. 119.—Percentage Decrease in Full Load Steam Consumption per Degree Centigrade Increase of Superheat in Parsons Turbines.

TABLE XLI.

K.W. rated Output.	Increase in Superheat.	Per cent. vacuum.	Percentage decrease in steam consumption, due to the increase in superheat, for the following percentages of full rated load.					Remarks.
			20%	40%	60%	80%	100%	
	°C							
3200	50 to 105	90	14·0	13·0	13·0	13·0	13·0	Interpolated from curves in Fig. 111.
1250	0 to 55·5	93·5	9·0	8·5	8·0	7·0	6·5	Interpolated from curves in Fig. 112.
1250	0 to 42·5	92·2	10·5	8·3	8·0	7·5	7·2	Interpolated from a mean of curves (A and C) and (B and D) in Fig. 113.
400	0 to 55·5	93·5	11·5	11·0	10·5	10·5	10·5	Interpolated from curves A and B in Fig. 114.
400	0 to 100	93·5	...	...	25·0	25·0	25·0	Interpolated from curves A and C in Fig. 114.

The next step consists in reducing the test results set forth in Table XXXVII. to a common basis of 86·6 per cent. vacuum and 50° Cent. of superheat. The results thus reduced are set forth in Table XLII.

In order to further examine the effect on the steam economy of variations in the admission pressure, all those tests in which

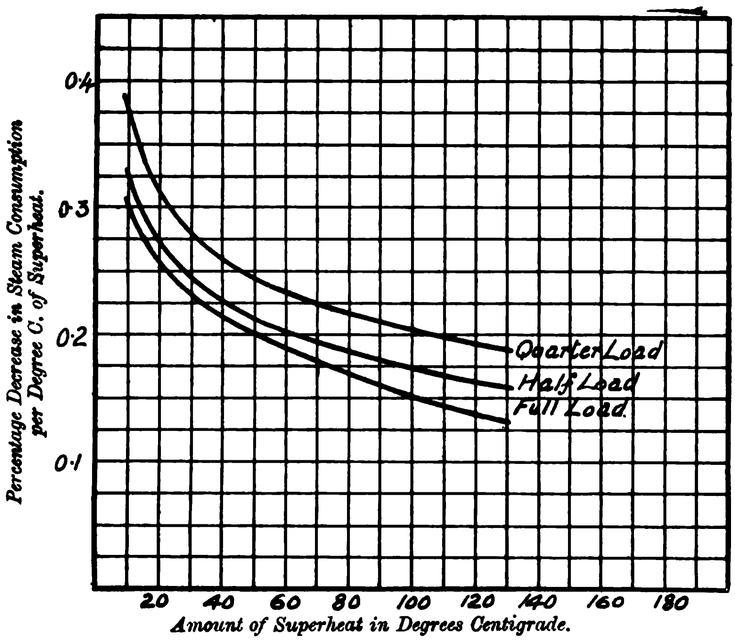


FIG. 120.—Percentage Decrease in Steam Consumption of a Parsons Turbine at Full, Half, and Quarter Load per Degree Centigrade Increase of Superheat.

the admission pressure was above 10 absolute metric atmospheres per square centimetre have been brought together in Table XLIII., for which the absolute admission pressure has been taken at the average value of 12·5 metric atmospheres. Those tests in which the admission pressure was 10 and less than 10 absolute metric atmospheres have all been brought together in Table XLIV., for which the average pressure is 8 absolute metric atmospheres.

[TABLE XLII.

Table XLII.—Showing the Steam Consumption with a Constant Vacuum of 86·6 per cent. and 50° Cent. of Superheat for the Parsons Steam Turbine, with Varying Absolute Steam Pressures, as derived from the Test Results on Table XXXVII.

Reference Number.	Kilowatts Output.	Steam Consumption in Kgs. per K.W. Hour for various percentages of Full Rated Load.											
		20%.		40%.		60%.		80%.		100%.		120%.	
		Steam Consumption.	Pressure.	Steam Consumption.	Pressure.	Steam Consumption.	Pressure.	Steam Consumption.	Pressure.	Steam Consumption.	Pressure.	Steam Consumption.	Pressure.
I.	24	23·2	6·22	18·10	6·35	14·00	6·50	13·7	6·6	13·4	6·60	..	..
II.	50	..	..	..	..	..	...	..	..	12·6	9·90	..	..
III.	75	..	..	..	..	15·20	11·10	13·4	11·00	12·5	11·00	..	..
IV.	100	..	..	17·20	7·83	15·20	7·70	13·5	7·55	12·8	7·60	11·90	7·72
	100	..	..	..	..	..	..	..	..	..	..	11·75	10·25
	100	..	..	15·10	9·90	13·50	9·90	12·0	9·90	11·5	9·90	11·10	9·90
	100	..	..	15·58	8·70	14·00	8·70	12·2	8·70	11·6	8·70	11·40	8·70
V.	135	..	..	14·65	11·70	12·65	11·70	11·5	11·70	11·2	11·70	11·00	11·70
VI.	200	..	..	..	..	..	..	..	..	10·20	8·40	10·5	9·80
	200	..	..	14·40	10·60	12·40	10·60	10·5	10·60	10·3	10·60	..	..
	200	..	..	13·70	12·50	11·80	12·50	10·7	12·50	10·5	12·50	..	..
VII.	250	..	..	19·80	10·10	16·40	10·00	14·9	10·00	13·10	10·00	13·00	10·00
	250	..	..	14·00	9·90	12·20	9·90	10·9	9·90	10·20	9·90	10·00	9·90
VIII.	300	..	..	13·20	11·60	11·70	11·60	10·5	11·60	10·1	11·60	9·95	11·60
	300	..	..	..	..	..	..	..	..	10·00	11·00	..	..
	300	..	..	13·50	10·00	11·80	10·00	10·80	10·00	10·40	10·00	..	..
	300	..	..	12·40	9·00	11·25	9·00	10·20	9·00	10·00	9·00	..	..
IX.	350	..	..	13·00	11·50	11·50	11·50	10·40	11·50	9·90	11·50	9·60	11·50
	350	..	..	13·50	11·20	11·90	11·20	10·60	11·20	9·30	11·20	9·40	11·20
	350	..	..	12·70	11·50	10·90	11·50	10·30	11·50	9·70	11·50	9·42	11·50
X.	375	..	..	..	..	..	..	..	..	10·00	11·60	..	..
	375	..	..	...	..	..	..	..	..	9·50	10·85	..	..
XI.	400	..	..	11·70	11·00	10·50	11·00	9·95	11·00	9·50	11·00	9·35	11·00
	400	..	..	11·60	7·50	10·00	7·50	9·10	7·50	9·00	7·50	..	..
	400	..	..	..	..	..	..	8·90	9·00	8·80	9·00	..	..
	400	12·20	11·90	10·10	11·90	9·50	11·90	9·25	11·90	9·00	11·90	8·90	11·90
	400	13·50	11·60	11·20	11·60	10·20	11·60	9·55	11·60	8·95	11·60	8·95	11·60
	400	14·20	11·60	12·10	11·60	10·80	11·60	10·10	11·60	9·50	11·60	9·18	11·60
	400	..	..	..	..	..	..	..	..	9·40	11·60	9·20	11·60
	400	13·40	11·60	12·00	11·60	10·25	11·60	9·40	11·60	9·20	11·60	9·10	11·60
	400	13·80	9·80	11·60	9·80	10·50	9·80	9·80	9·80	9·35	9·80	9·35	9·80
	400	12·70	11·00	11·30	11·60	9·85	11·60	9·05	11·60	8·20	11·00	8·15	11·60
	400	12·10	11·60	10·30	11·60	9·10	11·60	8·60	11·60	8·50	11·60	8·50	11·60
	400	..	..	12·25	11·60	10·50	11·60	9·90	11·60	9·60	11·60	9·50	11·60
	400	..	..	11·10	11·60	10·20	11·60	9·60	11·60	9·25	11·60	9·25	11·60

TABLE XLII.—*continued.*

Reference Number.	Kilowatts Output.	Steam Consumption in Kgs. per K.W. Hour for various Percentages of Full Rated Load.											
		20%.		40%.		60%.		80%.		100%.		120%.	
		Steam Consumption.	Pressure.	Steam Consumption.	Pressure.	Steam Consumption.	Pressure.	Steam Consumption.	Pressure.	Steam Consumption.	Pressure.	Steam Consumption.	Pressure.
XII.	500	..	..	13·80	10·15	11·30	10·15	10·00	10·15	9·50	10·15	9·30	10·15
	500	..	..	..	..	..	..	..	..	10·60	11·00	..	..
	500	..	..	..	..	..	..	..	..	9·45	11·40	..	..
	500	..	..	12·80	10·00	11·20	10·00	10·40	10·00	9·65	10·00	9·30	10·00
XIII.	750	..	..	12·30	11·60	11·00	11·60	10·00	11·60	9·50	11·60	9·10	11·60
	750	15·20	11·60	11·80	11·60	10·30	11·60	9·75	11·60	..	..	..	..
	750	14·80	11·60	11·40	11·60	10·10	11·60	9·10	11·60	8·80	11·60	8·50	11·60
	750	..	..	11·70	11·60	10·00	11·60	9·00	11·60	8·65	11·60	8·40	11·60
	750	..	..	11·60	11·60	10·50	11·60	9·45	11·60	8·80	11·60	8·60	11·60
	750	..	..	11·00	11·60	9·90	11·60	9·25	11·60	8·90	11·60	8·60	11·60
	750	..	..	11·40	11·60	9·95	11·60	9·2	11·60	8·60	11·60	8 30	11·60
	750	..		11·40	11·60	9·95	11·60	9·2	11·60	8·60	11·60	8·50	11·60
XIV.	1000	17·50	10·14	12·40	10·30	10·50	10·60	10·00	10·76	9·5	10·47	9·40	10·11
	1000	..	..	..	..	..	..	..	..	9·6 0	12·3	..	..
	1000	..	..	11·90	11·60	9·80	11·60	9·30	11·60	9·00	11·60	8·60	11·60
	1000	14·40	10·20	11·65	10·20	10·20	10·20	9·20	10·20	8·70	10·20	8·50	10·20
	1000	..	..	10·20	11·60	9·80	11·60	9·35	11·60	9·10	11·60	8·30	11·60
XV.	1100	..	..	..	..	10·70	10·30	9·30	10·30	9·10	10·30	9·00	10·30
XVI.	1250	14·40	11·50	11·30	11·50	9·65	11·50	9·05	11·50	8 60	11·50	..	..
	1250	13·65	11·50	10·90	11·50	9·65	11·50	8·70	11·50	8·45	11·50	8·25	11·50
	1250	14·00	11·40	11·20	11·40	10·10	11·40	9·25	11·40	9·10	11·40	8·90	11·40
	1250	14·30	11·50	11·80	11·50	10·30	11·50	9·20	11·50	8·85	11·50	8·70	11·50
	1250	14·20	11·50	11·80	11·50	10·40	11·50	9·60	11·50	9·25	11·50	9·00	11·50
XVII.	1500	13·00	14·80	10·85	14·80	9·40	14·80	8·70	14·80	8·35	14·80	8·15	14·80
	1500	..	..	11·00	10·80	9·85	8·60	9·50	7·60	8·35	7·00	..	..
	1500	..	..	11·30	10·70	9·20	10·70	8·85	10·70	8·15	10·70	..	..
	1500	13·00	11·60	10·75	11·60	9·30	11·60	8·70	11·60	8·30	11·60	8·10	11·60
	1500	12·30	11·60	10·60	11·60	10·40	11·60	8·80	11·60	8·45	11·00	8·25	11·60
	1500	14·10	11·60	11·40	11·60	9·70	11·60	8·95	11·60	8·50	11·60	8·40	11·60
XVIII.	2600	..	..	..	..	..	..	8·40	14·00	8·00	14·00	7·70	11·70
XIX.	3000	..	..	10·00	10·70	8·50	11·20	8·10	12·80	7·80	10·80	..	..
	3000	..	..	..	..	8·40	12·80	7·40	13·00	6·72	10·70	..	..
	3000	..	..	9·90	11·00	8·10	11·00	8·00	11·00	7 ·70	11·00	..	..
XX.	3200	12·65	10·00	9·85	10·00	8·60	10·00	8·20	10·00	8·05	10·00	..	..
	3200	11·60	10·00	9·40	10·00	8·20	10·00	7·80	10·00	7·80	10·00	..	..
	3200	12·50	14·00	9·60	14·00	8·10	14·00	7·45	14·00	7·35	14·00	..	..
XXI.	5500	10·00	12·65	8·42	12·65	7·42	12·65	6·82	12·65	6·50	12·65	6·60	12·65
	5500	10·50	12·65	9·10	12·65	8·30	12·65	7·70	12·65	7·20	12·65	7·32	12·

TABLE XLIII.—SHOWING THE STEAM CONSUMPTION AT A MEAN ABSOLUTE STEAM PRESSURE OF 12·5 KGS. PER SQ. CM., AN 86·6 PER CENT. VACUUM, AND 50° CENT. OF SUPERHEAT, FOR THE PARSONS STEAM TURBINE. (FROM TABLE XLII.)

Reference Nos. as in Table XLII.	Steam Consumption in Kgs. per K.W. Hour for various Percentages of Full Rated Load.						
	Kilowatts Output.	20%	40%	60%	80%	100%	120%
III.	75	...	...	15·20	13·40	12·50	...
V.	135	...	14·65	12·65	11·50	11·20	11·00
IV.	100	...	...	...	...	...	11·75
VI.	200	...	14·40	12·40	10·50	10·30	...
	200	...	13·70	11·80	10·70	10·50	...
VIII.	300	...	13·20	11·70	10·5	10·10	9·95
	300	...	...	...	...	10·0	...
IX.	350	...	12·70	10·90	10·30	9·70	9·42
	350	...	13·50	11·90	10·60	9·80	9·40
	350	...	13·00	11·50	10·40	9·90	9·60
X.	375	...	...	...	...	10·0	...
	375	...	...	...	...	9·50	...
XI.	400	...	11·70	10·50	9·95	9·50	9·35
	400	12·20	10·10	9·50	9·25	9·00	8·90
	400	13·50	11·20	10·20	9·55	8·95	8·95
	400	14·20	12·10	10·80	10·10	9·50	9·18
	400	...	...	...	...	9·40	9·20
	400	13·40	12·00	10·25	9·40	9·20	9·10
	400	12·70	11·30	9·65	9·05	8·20	8·15
	400	12·10	10·30	9·10	8·60	8·50	8·50
	400	...	12·25	10·5	9·9	9·6	9·5
	400	...	11·1	10·2	9·60	9·25	9·25

TABLE XLIII.—*continued.*

Reference Nos. as in Table XLII.	Steam Consumption in Kgs. per K.W. Hour for various Percentages of Full Rated Load.						
	Kilowatts Output.	20%	40%	60%	80%	100%	120%
XII.	500	...	13·80	11·30	10·0	9·50	9·30
	500	...	...	...	...	10·60	...
	500	...	...	...	...	9·45	...
XIII.	750	...	12·3	11·0	10·0	9·5	9·1
	750	15·2	11·8	10·3	9·75	...	...
	750	14·8	11·4	10·1	9 1	8·8	8·5
	750	...	11·7	10·0	9·0	8·65	8·4
	750	...	11·6	10·5	9·45	8·8	8·6
	750	...	11·0	9·9	9·25	8·9	8·6
	750	...	11·4	9·95	9·2	8·6	8·3
	750	...	11·4	9·95	9·2	8·6	8·5
XIV.	1000	17·5	12·40	10·50	10·0	9·50	9·40
	1000	...	...	...	...	9·60	...
	1000	...	11·90	9·80	9·30	9·0	8·6
	1000	14·40	11·65	10·20	9·20	8·70	8·50
	1000	...	10·2	9·8	9·35	9·1	8·8
XV.	1100	...	...	10·70	9·30	9·10	9·00
XVI.	1250	14·40	11·30	9·65	9·05	8·60	...
	1250	13·65	10·90	9·65	8·70	8·45	8·25
	1250	14·00	11·20	10·10	9·25	9·10	8·90
	1250	14·30	11·80	10·30	9·20	8·85	8·70
	1250	14·20	11·80	10·40	9·60	9·25	9·00

TABLE XLIII.—*continued.*

Reference Nos. as in Table XLII.	Steam Consumption in Kgs. per K.W. Hour for various Percentages of Full Rated Load.						
	Kilowatts Output.	20%	40%	60%	80%	100%	120%
XVII.	1500	13·00	10·85	9·40	8·70	8·35	8·15
	1500	...	11·30	9·20	8·35	8·15	...
	1500	13·00	10·75	9·30	8·70	8·30	8·10
	1500	12·30	10·60	10·40	8·80	8·45	8·25
	1500	14·10	11·40	9·70	8·95	8·50	8·40
XVIII.	2600	...	...	...	8·40	8·00	7·70
XIX.	3000	...	...	8·40	7·40	6·72	...
	3000	...	10·00	8·50	8·10	7·80	...
	3000	...	9·90	8·10	8·00	7·70	...
XX.	3200	12·50	9·60	8·10	7·45	7·35	...
XXI.	5500	10·00	8·42	7·42	6·82	6·50	6·60
	5500	10·50	9·10	8·30	7·70	7·20	7·32

In Fig. 121 the results at rated full load from Table XLIII. (12·5 absolute atmospheres) are plotted as circles, and the results at rated full load from Table XLIV. (8 absolute atmospheres) have been plotted as crosses. All these observations are evidently represented fairly well enough for practical purposes by the single curve of the figure.

In the same way, the curves of Figs. 122 and 123 show the average results at half load and quarter load to be practically independent of the pressure.

The three firms who have manufactured the greatest number of turbines of the Parsons type, namely, C. A. Parsons & Co., Westinghouse Co., and Brown-Boveri, have obtained practically identical results as regards steam economy. This is seen in Table XLV., where have been brought together, in such a way as to permit of comparison in this respect, the results of the published tests on sets of from 300 to 500 kilowatt capacity, this being the range of sizes for which all three

TABLE XLIV.—SHOWING THE STEAM CONSUMPTION AT A MEAN ABSOLUTE STEAM PRESSURE OF 8·0 KGS. per SQ. CM., AN 86·6 PER CENT. VACUUM, AND 50° CENT. SUPERHEAT, FOR THE PARSONS STEAM TURBINE. (FROM TABLE XLII.)

Reference No.	Kwts. Output.	Steam Consumption in Kgs. per K.W. Hour for various Percentages of Full Rated Load.					
		20%	40%	60%	80%	100%	120%
I.	24	23·20	18·10	14·00	13·70	13·40	...
II.	50	...	...	...	...	12·60	...
IV.	100	...	15·10	13·50	12·00	11·50	11·10
	100	...	15·85	14·00	12·20	11·60	11·40
	100	...	17·20	15·20	13·50	12·80	11·90
V.	200	...	...	...	...	10·20	10·50
VII.	250	...	19·80	16·40	14·90	13·10	13·60
	250	...	14·00	12·20	10·90	10·20	10·00
VIII.	300	...	13·50	11·80	10·80	10·40	...
	300	...	12·40	11·25	10·20	10·00	...
XI.	400	...	11·60	10·00	9·10	9·00	...
	400	...	...	...	8·90	8·80	...
	400	13·30	11·60	10·50	9·80	9·35	9·35
XII.	500	...	12·80	11·20	10·40	9·65	9·30
XVII.	1500	...	11·00	9·85	9·50	8·35	...
XX.	3200	12·65	9·85	8·60	8·20	8·05	...
	3200	11·60	9·40	8·20	7·80	7·80	...

firms have published enough tests to permit of a useful comparison.

Our analysis of the economy tests of the Parsons type of turbine shows the percentages increase in steam consumption with decreasing load to be of the values set forth in Tables XLVI. and XLVII.

In Table XLVI. we have set forth figures showing representa-

TABLE XLV.—SHOWING THE STEAM CONSUMPTION FOR VARIOUS MAKES OF THE PARSONS STEAM TURBINE AT VARYING LOADS, WITH AN ABSOLUTE STEAM PRESSURE RANGING FROM 7·5 TO 12·5 KGS. PER SQ. CM. AT A CONSTANT VACUUM OF 86·6 PER CENT. AND 50° C. OF SUPERHEAT.

Reference Number.	Kilowatts Output.	20% Parsons.	20% Brown-Boveri-Parsons.	20% Westinghouse-Parsons.	40% Parsons.	40% Brown-Boveri-Parsons.	40% Westinghouse-Parsons.	60% Parsons.	60% Brown-Boveri-Parsons.	60% Westinghouse-Parsons.	80% Parsons.	80% Brown-Boveri-Parsons.	80% Westinghouse-Parsons.	100% Parsons.	100% Brown-Boveri-Parsons.	100% Westinghouse-Parsons.	120% Parsons.	120% Brown-Boveri-Parsons.	120% Westinghouse-Parsons.
VIII.	300	..	..	..	14·4	13·5	..	12·4	11·8	..	10·5	10·8	..	10·3	10·4	..		..	..
	300	..	..	..	..	12·4	..	..	11·25	..	..	10·2	..	10·0	10·0	..	..	..	..
IX.	350	..	..	..	13·0	12·7		11·5	10·9	..	10·4	10·3	..	9·7	9·7	..	9·6	9·42	..
	350	..	..	..	13·5	..	..	11·9	..	..	10·6	..	..	9·8	..		9·4	..	..
X.	375	..	..	..	.	..	..	..	..	..	..	..	..	10·0	..		..	..	..
	375	..	..	..	..	..	..	..	..	..	..	..	..	9·5	..	..	..	..	..
XI.	400	..	..	12·2	..	11·7	10·1	..	10·5	9·5	..	9·95	9·25	..	9·5	9·0	..	9·35	8·9
	400	..	.	13·5	..	11·6	11·2	..	10·0	10·2	..	9·1	9·55	..	9·0	8·95	..	..	8·95
	400	.	..	13·4	..	..	12·0	..	..	10·25	..	8·9	9·4	..	8·8	9·4	..	..	9·1
	400	..	..	14·2	..	..	12·1	..	..	10·8	..	..	10·1	..	..	9·5	..	..	9·18
	400	..	..	13·3	..	..	11·6	..	..	10·5	..	..	9·8	..	..	9·35	..	..	9·35
	400	..	..	12·7	..	..	11·3	..	..	9·85	..	..	9·05	..	..	8·2	.		8·15
	400	..	..	12·1	..	..	10·3	..	..	9·1	..	..	8·6	..		8·5	.	..	8·5
	400	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8·1	..	..	8·0
	400	..	..	..	..	..	12·25	..	..	10·6	..	..	9·9	..	..	9·6	..	..	9·5
	400	..	..	..	..	..	11·1	..	..	10·2	..	..	9·6	..	..	9·25	..	..	9·25
XII.	500	..	..	..	..	..	..	..	..	..	..	..	..	10·7	..	..	..	..	..
	500	..	..	..	13·8	12·8	..	11·3	11·2	..	10·0	10·4	.	9·5	9·65	..	9·3	9·3	..
	500	..	..	..	..	..	..	..	..	..	..	..	..	10·6	..	..	..	..	..

Column heads as printed: MAKER OF TURBINE. — Steam Consumption in Kgs. per K.W. Hour for Various Percentages of Full Rated Load.

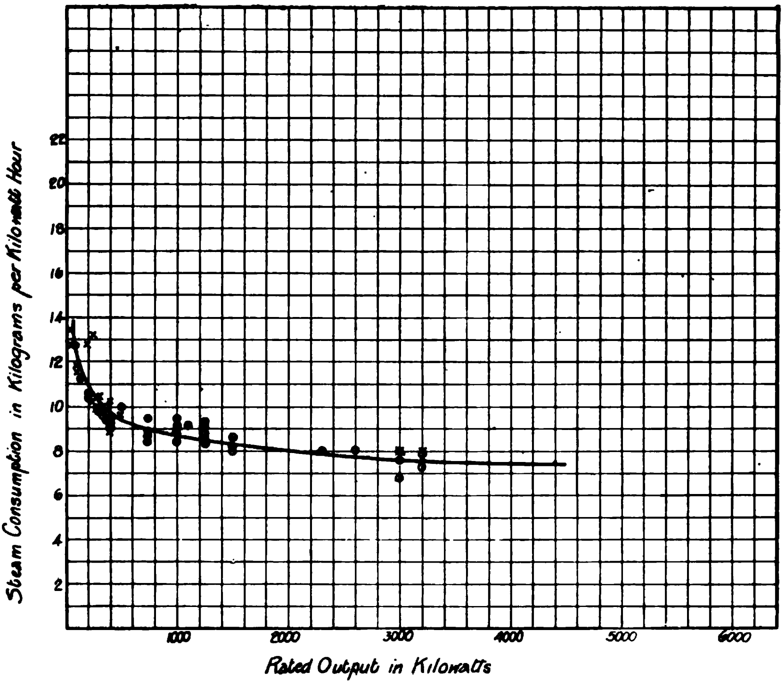


FIG. 121.—Full Rated Load.

Steam Consumption : Parsons Turbines.
O = 12·5 Kgs. Abs. from Table XLIII.
X = 8 ,, ,, XLIV.
50° C. Superheat ; 86·6 per cent. Vacuum.

TABLE XLVI.—SHOWING THE AVERAGE STEAM CONSUMPTION OF TURBINES OF THE PARSONS TYPE AT FULL, HALF, AND QUARTER RATED LOADS, WITH 86·6 PER CENT. VACUUM (26 INCHES) AND 50° C. SUPERHEAT.

Rated Output K.W.	Steam Consumption in Lbs. and Kgs. per K.W. Hour.					
	Full load.		Half load.		Quarter load.	
	Lbs.	Kg.	Lbs.	Kg.	Lbs.	Kg.
250	23	10·5	28·2	12·8	37·5	17
500	20·5	9·3	25	11·3	32	14·5
1000	19	8·6	22·7	10·3	29	13·2
2000	17·6	8·0	21	9·6	26·7	12·1
4000	16·3	7·4	19·3	8·8	24·5	11·1

tive values of steam consumption for Parsons type turbines, based on the numerous test results given in this chapter, and already shown in the mean curves in Figs. 121, 122, and 123.

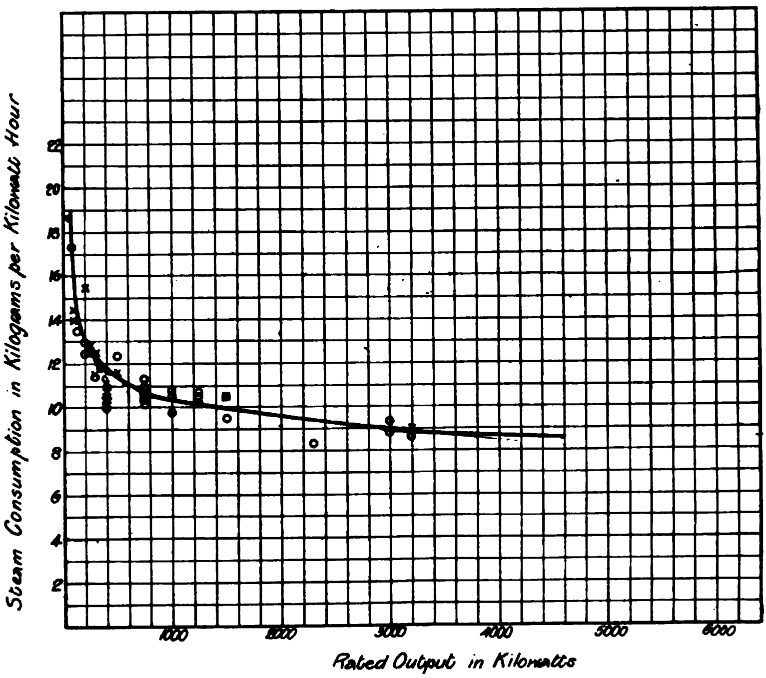


Fig. 122.—Half Rated Load.

Table XLVII., derived from the previous table, shows the percentage by which the steam consumption at half and quarter rated load exceeds the consumption at full load. It may be noted, that

TABLE XLVII.

Rated Output K.W.	Percentage by which the Steam Consumption per K.W. Hour exceeds that at Full Load, Vacuum 86·6 per cent., Superheat 50° C.	
K.W.	Half load.	Quarter load.
250	22 per cent.	62 per cent.
500	21 „	56 „
1000	20 „	54 „
2000	20 „	52 „
4000	19 „	50 „

as the size of the unit is increased, there is a diminution in this excess.

The figures given in these two tables are all for our standard conditions, viz. vacuum 86 per cent. (26 inches) and 50° C. superheat.

In the *Marine Rundschau* for January 1904 are given some interesting particulars of a 65 kilowatt, 110 volt Brown-Boveri-

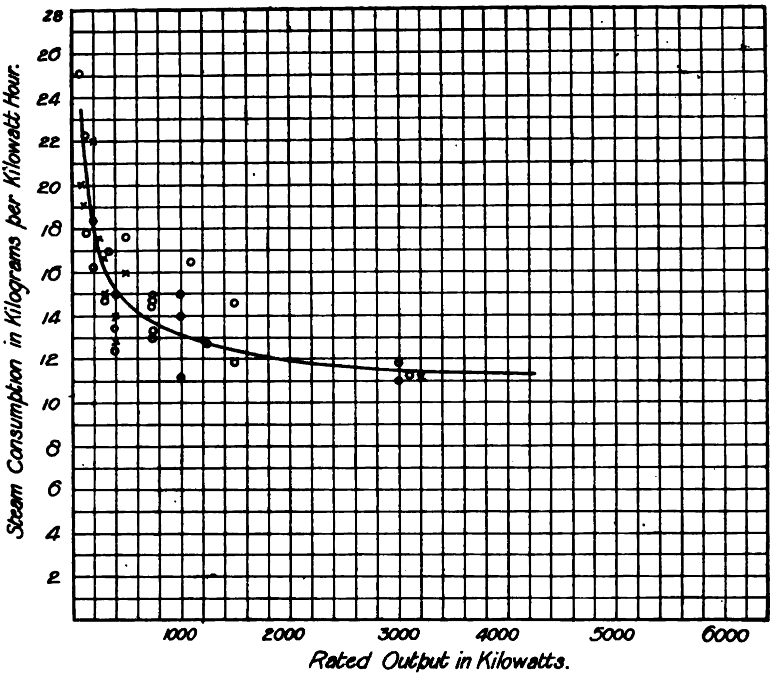


FIG. 123.—Quarter Rated Load.

FIGS. 122 and 123.—Steam Consumption: Parsons Turbines.
O = 12·5 Kgs. Abs. from Table XLIII.
X = 8 „ „ XLIV.
50° C. Superheat; 86·6 per cent. Vacuum.

Parsons set, for use in marine lighting plants. The outline dimensions are shown in Fig. 124. The pressure, temperature, and vacuum are not given, but it is stated that the steam consumption was 18·8 kilograms per kilowatt-hour, and that a lower figure could have been obtained by an increase in the length of the turbine. The specification, however, only called for a steam consumption of from 18 to 19 kilograms per kilowatt-hour. It is stated that an increase in length of 0·5 metres would have

permitted of a design with a steam consumption of 17 kilograms per kilowatt-hour, and that its weight would be some 3000 kilograms. In a tender for supplying four of these 65 kilowatt

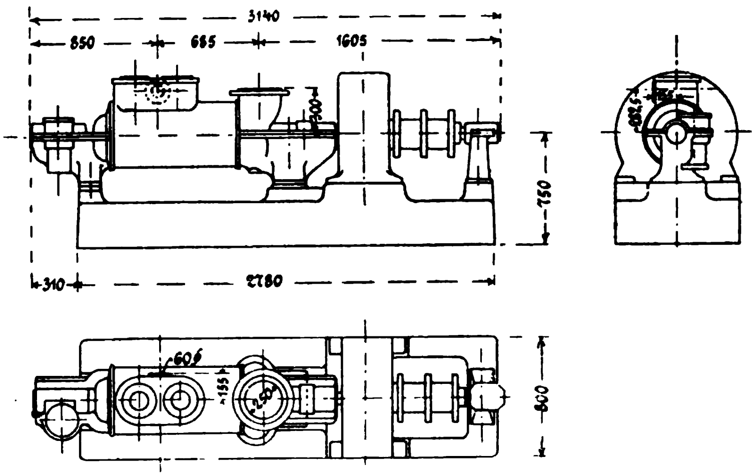


FIG. 124.—65 K.W. 110-volt Parsons Turbo-Generator.
Dimensions in Millimetres.
(Grauert, *Über Dampfturbinen.*)

sets to the German navy, the price was 86,000 marks, or about £1070 per set, or £16, 5s. per kilowatt. The price for an equivalent piston-engine set, such as has been extensively used for such plant, works out at £750, or about £11, 6s. per kilowatt.

CHAPTER V

THE CURTIS STEAM TURBINE

General Description.—Many attempts were made to produce a practical turbine embodying the de Laval nozzle which would run at lower speeds than the de Laval turbine, and a substantial measure of success was attained when machines were built by C. G. Curtis, about 1896, on the principle of removing the energy of the steam in successive stages, each stage consisting of a set of expansion nozzles and two or more rows of moving vanes with intervening guides, the total expansion of the steam taking place in steps in the nozzles, and the kinetic energy developed in each expansion being absorbed in the moving vanes of each stage. The steam pressure throughout each stage is practically the same, any slight difference in pressure between the different rows of vanes being only sufficient to overcome the friction of the vane passages. The steam is admitted to the first stage in an extended stream forming a segment of a circle and of a width equal to that of the wheel buckets. Curtis showed that in order to govern a turbine of this type economically the entering stream must be changed in cross section without changing its velocity, that is, without throttling, its width, of course, remaining constant; and in his early machines, which were of the horizontal type, provision was made for effecting this result.

In the Curtis machine, as developed in its present commercial form by the General Electric Company of New York, U.S.A., and made in England by The British Thomson-Houston Company, the shaft is arranged vertically, and the incoming stream is divided up into a number of sections composed of small nozzles closely packed together, so that practically a continuous belt of steam is formed (see Fig. 127). By so dividing up the stream the governing

arrangement is very much simplified, as each small nozzle or a group of nozzles may be controlled by a separate valve, and changes in load may be taken care of by shutting off or opening one or more of the nozzles, preferably those nozzles which will leave the belt continuous.

Vanes or Buckets.—Curved vanes or side walls to the passages in the earliest designs were *mounted* on one or more drums, and had a less angle at the discharge than at the receiving end, Fig. 125.

The latest practice puts a smaller angle at the entrance than at the discharge side.

Machining the Vanes.—By 1902 the vanes were machine

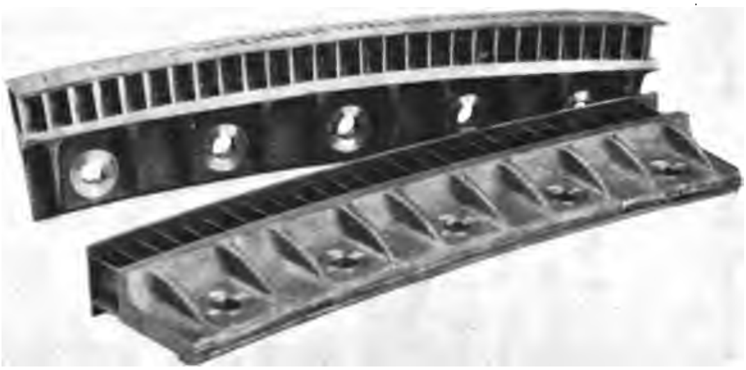


FIG. 125.—Revolving Vanes or Buckets for Curtis Turbine. These are bolted around the periphery of a disc.

cut out of solid metal around the circumference of a disc; special tools, on which numerous improvements have been made, having been designed for this work.

"Stages" or Pressure Steps.—The number of moving vanes or buckets against which the steam impinges between the admission nozzles and the condenser varies in different designs, and the tendency in new designs is to increase the number.

The smallest units (on horizontal shafts) are built with one stage, and the largest have in recent cases four and five stages. Fig. 126 shows the revolving part of the second stage of a 500 kilowatt two-stage unit.

Steam Economy.—The degree of expansion desired and the

peripheral speed determine the number of stages and number of rows of vanes in each stage.[1]

Mr A. H. Kruesi,[2] in a paper read in 1903, said, "Greater

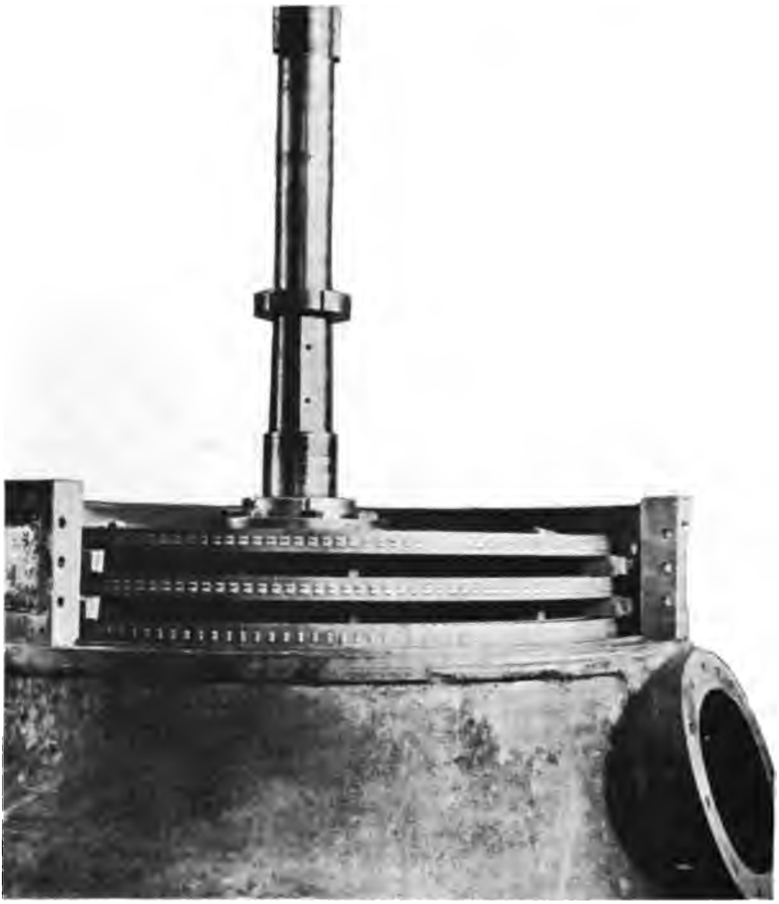


FIG. 126.—Bucket Wheels and Intermediates. Second Stage of 500 K.W. Two-Stage American Curtis Turbine.

economy is probably due to the fact that the steam is more effectively directed against the wheels by the nozzles than by intermediate stationary vanes."

[1] The same angle at receiving and discharge end was used in first 600 kilowatt Curtis turbines (two-stage six rows revolving vanes, four rows stationary vanes, two sets nozzles). Page 2, "The Steam Turbine in Modern Engineering," by W. L. R. Emmet, Chicago, 1904, American Society of Mechanical Engineers.

[2] Association of Edison I. Companies, 24th Convention, September 1903.

The 5000 kilowatt units illustrated in W. L. R. Emmet's Chicago paper[1] shows only two stages (*i.e.* two sets of expanding nozzles), with four rows of revolving vanes in each stage.

The Newport machines mentioned in the same paper[1] are 500 kilowatt units, and have only two stages with three rows of revolving vanes per stage.

The later designs of every size from 500 kilowatts upwards have at least four stages. One seven-stage machine is in the list, p. 209.

The delivery side of a row of first-stage nozzles for a 2000 kilowatt unit is shown in Fig. 127; and as the partitions are

FIG. 127.—First-Stage Nozzle for 2000 K.W. Curtis Steam Turbine.

reduced here to knife edges, it is clear that the expanded steam enters in practically a single belt.

Diaphragms between Stages.—A diaphragm containing intermediate nozzles is placed between successive stages.

This reduces the leakage area around the shaft to an annulus of comparatively small diameter, and the makers claim that the diaphragm is practically steam-tight.

Fig. 128 shows a diaphragm with twenty-eight expanding nozzles.

Synchronising.—For synchronising and for adjusting the load between several units, each main governor has a supplementary spring which alters the speed corresponding to a given load about 2½ per cent. on either side of normal without affecting the regulation. The regulation can be altered by adjustments of the governor weights.

[1] American Society of Mechanical Engineers, Chicago, June 1904.

In the units below 1500 kilowatts this supplementary spring is controlled by a hand wheel (see Fig. 129).

For 1500 kilowatt units and larger sizes a small motor actuates this spring (see Fig. 130). The motor is usually controlled at the main switchboard by a double pole reversing switch.

Marine Work.—For marine work two concentric sets of vanes having opposite curvatures were designed, each set having separate nozzles fixed at correct angles to give rotation in one direction.

FIG. 128.—Diaphragm showing Twenty-eight Nozzles.

Expanding Nozzles.—Mr Curtis' governor admitted the steam through a number of expanding nozzles; each[1] nozzle was connected to the steam supply and provided with an independent valve, so that its full bore was open or definitely closed. This device was introduced to avoid "wire drawing," only a fraction of the total steam being subjected to such treatment, as will be now explained. Fig. 127, page 194, shows ten such sections.[2]

The automatic control of speed requires a more delicate adjustment of steam supply than is provided by opening or closing a tenth (in this case) of the maximum steam admission area.

[1] In small turbines one valve supplies a pair of nozzles.

[2] From Table, p. 206, this appears to be for a 2000 kilowatt unit.

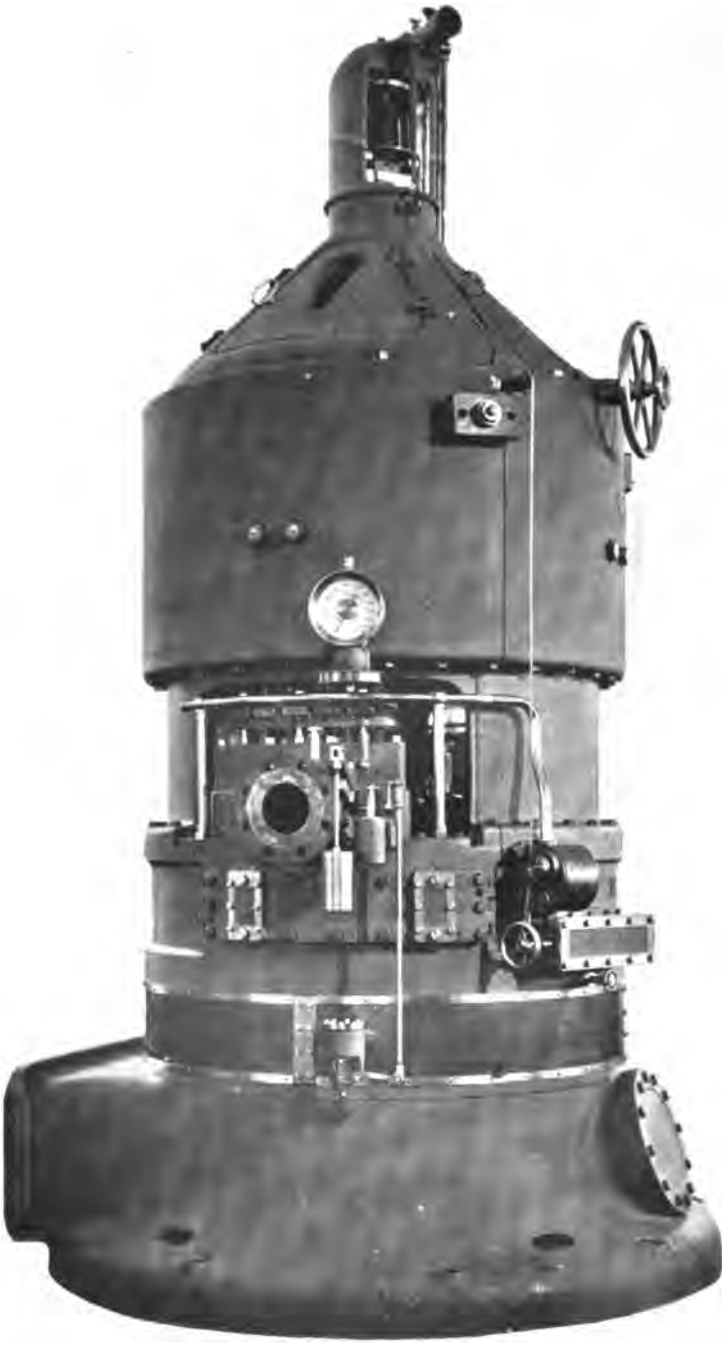


FIG. 129.—500 K.W. Vertical Two-Stage Curtis Turbine and 500 Volt Continuous Current Generator, 4 Poles 1800 R.p.m. (Cork Tramways.)

For this reason the first valve in each such set of valves supplies steam through a balanced throttle valve to the first nozzle, and the smaller variations are taken care of by this throttle.

The operation of the valves is arranged so that the throttle must be fully opened before another can open, and the throttle then assumes a position corresponding to the load, gradually opening or closing as more or less steam is required. When reducing the

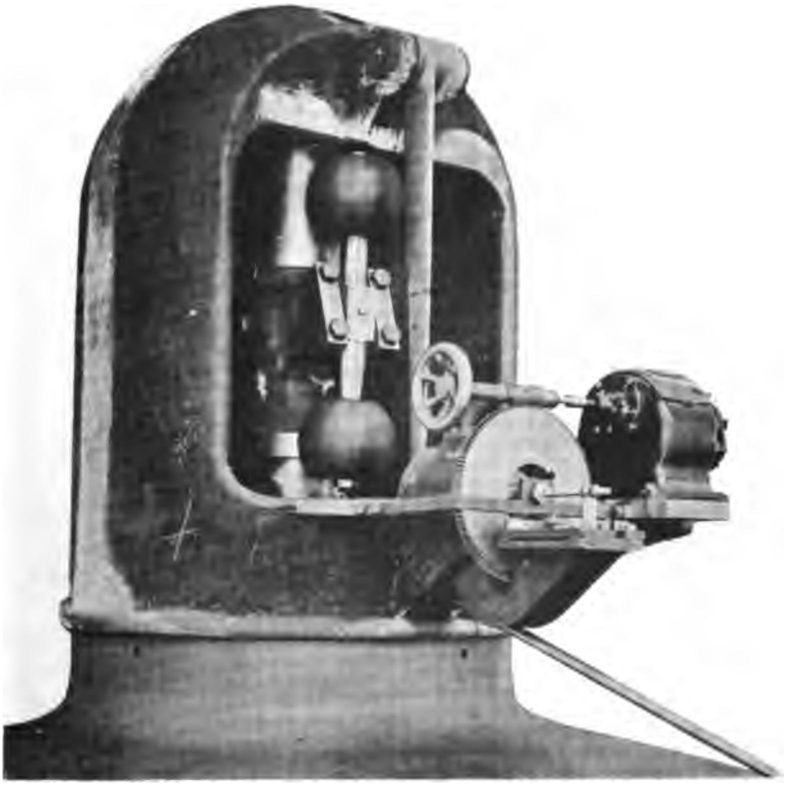


FIG. 130.—Governor and Synchronising Motor on a 5000 K.W. Curtis Turbine.

steam supply to a greater extent than the throttle can deal with, the throttle must be fully closed before another valve closes, then the throttle takes up a position corresponding to the new load conditions, receiving its motion from the governor. An increase in the governor speed closes the throttle, and a decrease in speed opens it.

In the standard control, which is illustrated schematically in Fig. 131, the governor A moves an electric controlling switch B,

which governs the circuits of a set of ironclad[1] magnets C, controlling a set of pilot valves D. The switch contacts are arranged so that the pilot valves open and close in a predetermined

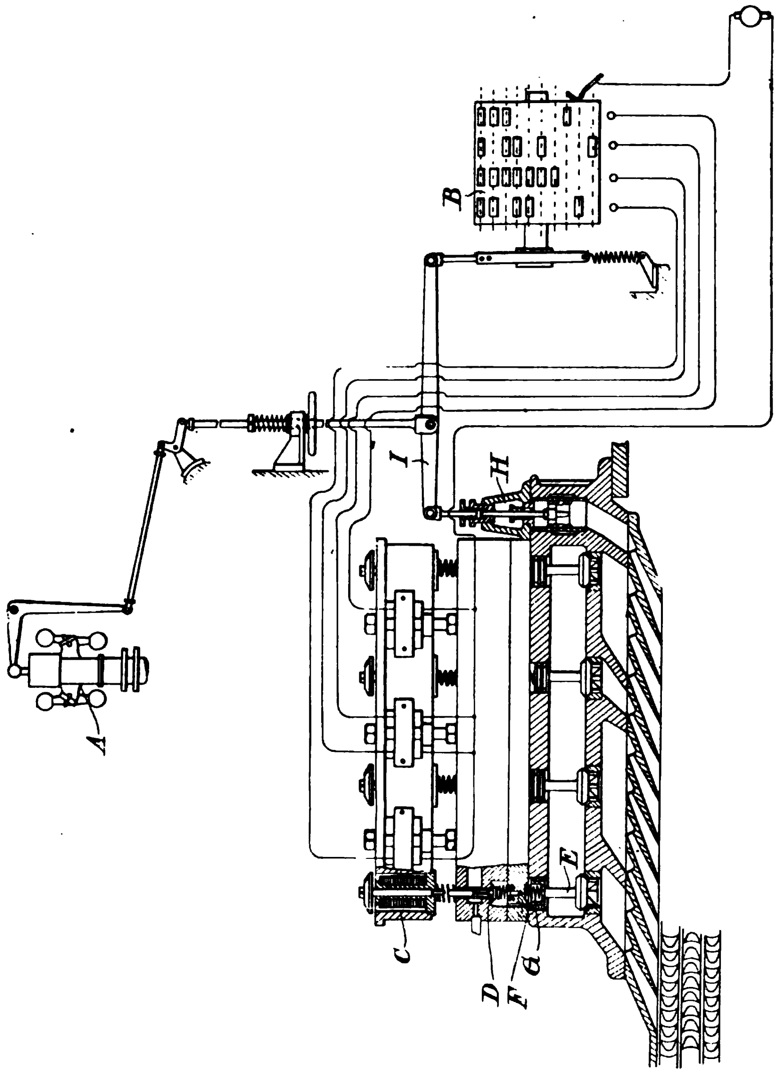


FIG. 131.—Curtis Turbine. A Set of Electrically-controlled Pilot Valves, Main Valves, Throttle Valve and Nozzles, with Samuelson's Improved Grouping.

sequence, dependent on the load conditions, and the operation of each pilot valve is followed by the operation of a corresponding

[1] For these electrical coils non-fibrous and non-flammable insulation is used which is said to withstand 500° F., but seldom is subjected to more than half that temperature.

nozzle valve E. The nozzle valves are opened by steam pressure admitted to and exhausted from the chamber F, the spring G serving normally to maintain the valve closed. The current for energising the electro-magnets is supplied from the exciter circuit.

In order to minimise the number of valves for taking care of a given load, all of the valves except one control more than a single nozzle. By a suitable arrangement of the controller connections, the groups of nozzles and the single nozzle may be combined together so as to give any desired regulation. With the arrangement illustrated, regulation of the power is possible in equal steps down to one-tenth of the full power of the machine. The finer regulation is accomplished by means of the throttle valve H; and in order that the throttling may have the minimum effect on the economy, this throttle valve only operates on the steam supply through a single nozzle. The throttle valve rod is connected to one end of a rocking lever I, the other end of which is attached to the controller actuating connection. The governor actuated mechanism is connected to the lever I at a point nearer the throttle valve rod than mid-position, so that the throttling always precedes each change of valve grouping effected by means of the controller, that is, the throttle valve always moves so as to attempt to take care of the change of load, and if it finds that it cannot do so the controller comes into operation, and causes the operation of another valve or valves.

Another arrangement of ironclad magnet and valves to a larger scale is shown in Fig. 132, and a third in Fig. 133.

Number of Nozzles.—Enough nozzles are provided to run the turbine at full load non-condensing, which is claimed to give the turbine an overload capacity of about 100 per cent. when operating condensing with 28″ vacuum; assuming, of course, there is sufficient boiler capacity installed to supply this extra quantity.

The number of valves, corresponding to the number of sections in the expanding nozzles, stated for some sizes of units on page 206 refer to the design prior to the adoption of groups of nozzles under one valve.

The variation of pressure in succeeding stages may be seen in the tests of 2000 kilowatt unit on page 221, which also gives corresponding temperatures and superheats.

Governor.—The governor is a spring-loaded centrifugal mechanism, mounted on the top of the shaft in vertical type Curtis turbines. It is illustrated in Fig. 129, 500 kilowatt size, and Fig. 130, 5000 kilowatt size.

As an alternative device, a type of pilot valves operated by cams on a shaft, moved by the aid of a hydraulic device under the control of the governor, has been made experimentally, but requires

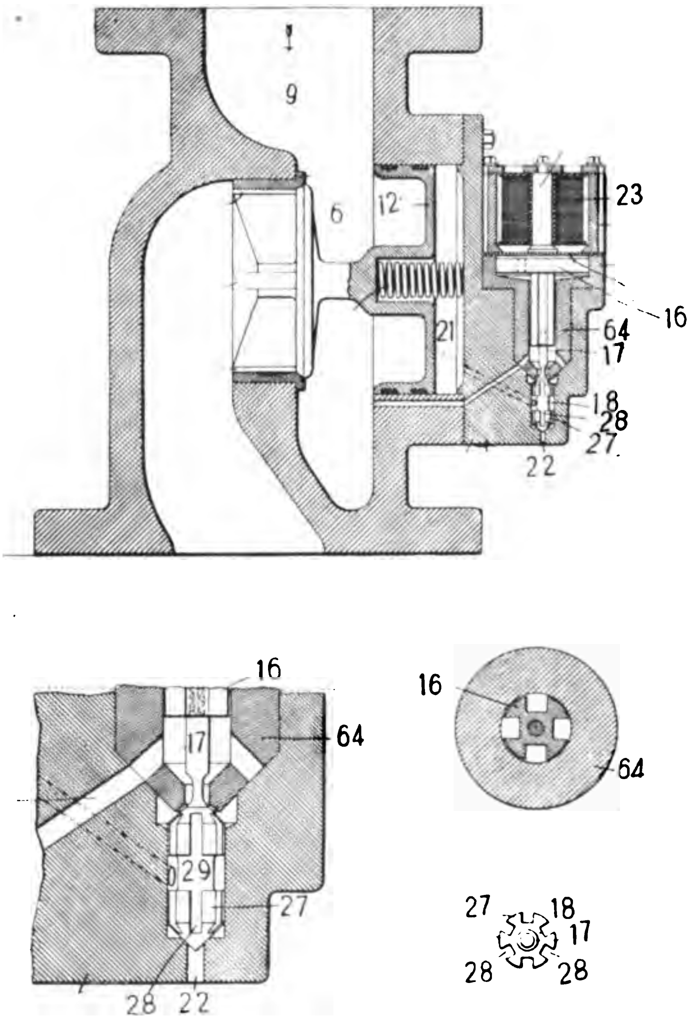


FIG. 132.—Another Arrangement of Electrically-controlled Pilot Valve and Main Valve.

Duplicate Parts bear the same Number in above three Illustrations.

an exceptionally powerful governor. This has not been developed commercially.

The governor is usually set for a speed regulation of 2 per cent. between full load and no load.

Emergency Governor.—On the shaft below the electric generator and above the steam turbine, in Curtis turbo-generators with vertical shafts, a centrifugal device balanced against a spring is located. This shuts off steam by tripping a trigger which drops a weight, instantaneously closing a butterfly valve in the main steam pipe when the speed of rotation exceeds a predetermined

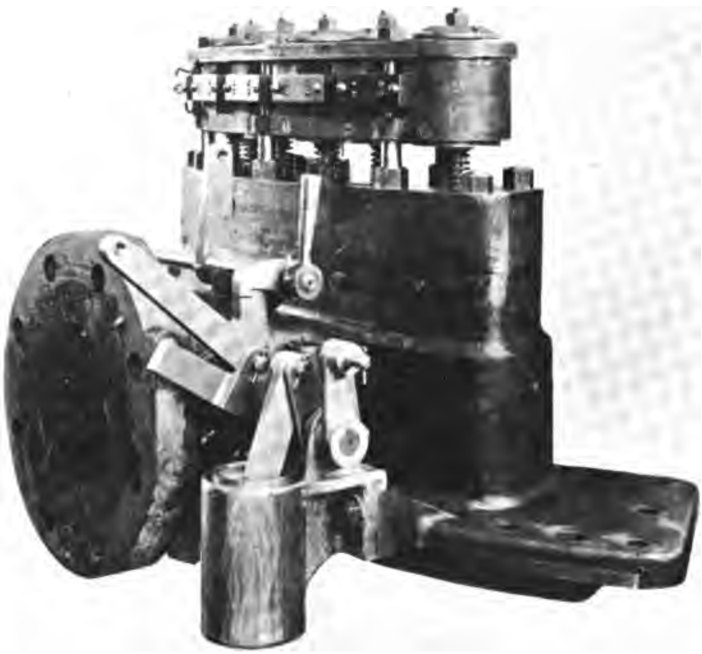


FIG. 133.—Electrically-operated Valves and Emergency Stop Valve Levers: 500 K.W. Curtis Turbine at Cork.

limit, usually 15 per cent. above normal. It is shown partly in Figs. 129 and 133, p. 196.

Vertical Shaft.—For driving electric generating machinery for units above 500 kilowatts the vertical shaft (already mentioned) was introduced, having a large footstep bearing, supplied with lubricant (oil or water) under such a pressure that it supports the weight of the rotating parts.

Obviously this gives the simplest shaft design.

Footstep Bearing.—The film of oil or water which supports the rotating parts is about ·005 inch thick.

TABLE XLVIII.—OIL SUPPLY[1] TO FOOTSTEP BEARING OF VERTICAL CURTIS TURBO-GENERATOR, WHEN OIL IS USED.

Unit.	Pressure lbs. per sq. inch.	Safe Flow per Minute.	Oil Pump Capacity.		When Oil is used for Footstep. Baffle Pressure for other Bearings.[2]
		Gallons.	Gallons.	Pressure.	
500 K.W.	180	1	2¼	225	45
1000 K.W.	380	...	3¾	475	95
2000 K.W.	420	...	3¾	525	105
3000 K.W.	520	...	3¾	650	130
5000 K.W.	640	4	6	800	160

[1] A. H. Kruesi, Denver, June 1905, Meeting National Electric Light Association,—"Operating Features of Vertical Curtis Steam Turbines."

[2] Concerning oil in other bearings, see p. 204, also p. 212.

FIG. 134.—Step Bearing for 2000 K.W. Curtis Steam Turbine.

The bearing consists of two circular cast-iron plates (Fig. 134), one being fixed to the shaft; through the other, the stationary plate, the oil or water is forced by a pressure pump.

This footstep block and the guide bearing can be lowered into the pit for renewal or examination without dismantling the machine.

A heavy screw, operated in the larger units by worm gear, supports the bearing block, and is used for adjustments of

Fig. 135.—Footstep Bearing, 5000 K.W. American Curtis Turbine.

clearances. Inspection holes are made in the casing for viewing the clearance when making adjustments.

With separate condenser arrangement or oil lubrication it is necessary to provide packing between the exhaust chamber and the atmosphere (Fig. 135). This packing consists of three carbon rings closely fitting the shaft, and having between the two upper

rings a low pressure of steam maintained to prevent leakage of oil into the condenser.

With water lubrication in the footstep the water discharges through a guide bearing, taking the place of the above packing between the atmosphere and the condenser. The water from these bearings passes off with the condenser discharge (see Fig. 136).

The amount of water is 3 per cent. to 5 per cent. of the amount

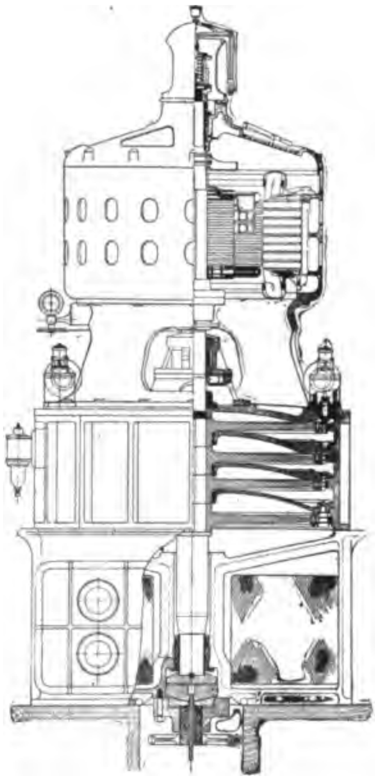


FIG. 136.—Curtis Turbo-Generator with Subbase Condenser.

used for steam. Except when running non-condensing, the supply for the footstep is taken from the air-pump discharge, thus neither adding nor taking water from the hot-well system. Water from the air-pump, being free from air and impurities, is most suitable for this purpose.

Other Bearings.—A tank, fed through a resistance from the footstep oil pump,[1] when oil is used for this delivers oil by gravity to the middle and upper bearings.

[1] See Baffle Pressure, Table XLVIII., p. 202.

The middle bearing is made in halves and can be removed sideways.

The upper bearing can be lifted off the end of the shaft after the governor has been removed.

Glands.—Packing is provided around the shaft below the upper bearing.

Quantity of Oil.—Through the upper and middle bearings the circulation amounts to—

10 gallons of oil per hour in a 500 kilowatt unit				
30	„	„	5000	„

the oil being strained and cooled after each passage through the bearings.

Accumulator.—An accumulator is supplied by the same means as the footstep, and it stores enough lubricant under pressure to keep the footstep supplied during some ten minutes During this period an audible signal calls attention to the fact that this reserve is being used up.

If the supply of lubricant to the footstep bearing is interrupted, or is less in pressure than it should be, a switch, which is held shut by that pressure, automatically opens the electric control circuit of the valve magnets, elsewhere described (p. 197).

The opening of this switch can also be made to close an auxiliary circuit, which on closing trips the circuit breaker of the generator. It is then impossible for the generator to receive current from other sources which might motor it. In fact, without this device such an accident did happen in Fisk Street station of the Commonwealth Electric Company of Chicago,[1] resulting in considerable damage, where three-phase, twenty-five cycle, 6600 volt, 5000 kilowatt Curtis turbo-alternators are installed, supplying rotaries which also draw power from another generating plant.

Condensers.—In the plants using Curtis turbines in Great Britain there are various types of surface condensers installed, with, we find, an average cooling surface of 3 square feet per rated kilowatt. In America the cooling surface installed varies from 3·6 to 4·3 square feet per rated kilowatt.

Subbase Condenser.—The vertical type of turbine lends itself to a special design of surface condenser immediately beneath the turbine, which offers advantages in the absence of many joints and in large passage for the low-pressure steam.

[1] *Power*, p. 548, September 1904, gives the Editor's explanation of this accident.

TABLE XLIX.—AREAS OF STEAM PASSAGES.

Curtis Turbines with Separate Condensers.

Size of units rated K.W.	Steam Admission. Diam. Inches.	Steam Admission. Area sq. in. per rated K.W.	No. of Valves Expanding Nozzle Sections.	To Atmosphere. Diam. Inches.	To Atmosphere. Area sq. in. per rated K.W.	To Condenser. Breadth. ins.	To Condenser. Height. ins.	To Condenser. Area sq. in. per rated K.W.
500	6	·057	...	12	·22	40	16	1·1
750								
800	6	·035	...	12	·14	68	14	1·2
1000	8	·05	...	16	·20	94	12	1·1
1500	10	·052	..	18	·17	110	16	1·1
2000	10	·039	20[1]	24	·22	100	24	1·2
3000	12	·038	24	30	·24	127	30	1·2
5000	14	·031	30	36	·22	162	36	1·1

Curtis Turbines with Subbase Condensers.

	Size of units rated K.W.	Steam Admission. Diam. Inches.	Steam Admission. Area sq. in. per rated K.W.	No. of Valves Expanding Nozzle Sections.	To Atmosphere. Diam. Inches.	To Atmosphere. Area sq. in. per rated K.W.	To Condenser. Breadth / Height	To Condenser. Area sq. in. per rated K.W.
Fulham	750	...	...	...	...	...	6′ diam.	5·3
Harrogate	750							
Hammersmith	1500							
County of London Co.	1500							
St Louis Exhibition	2000							
Boston [2]	5000	...	...	...	...	...	9′ 8″ diam.	2·2

[1] These antedate Mr F. Samuelson's improvement. With his grouping of nozzles under one valve the number of valves is reduced.

[2] Fig. 7, Emmet's Chicago Paper.

It is not apparent how such a set can be run non-condensing while repairs are being made to the condenser, as no condenser valve can be supplied of such area conveniently.[1] The atmospheric exhaust is about the middle of the stages at the side. A subbase type of condenser is in use at Fulham and Harrogate Corporations Electricity Works under 750 kilowatt Curtis turbo-alternators, at Hammersmith Corporation Electricity Works, and County of London Company's City Road and Wandsworth stations,

[1] See area of exhaust passages above.

under 1500 kilowatt units; also at Boston, Massachusetts, in Edison Electric Illuminating Company's plant, under 5000 kilowatt units (Figs. 386 to 390, pp. 543–547).

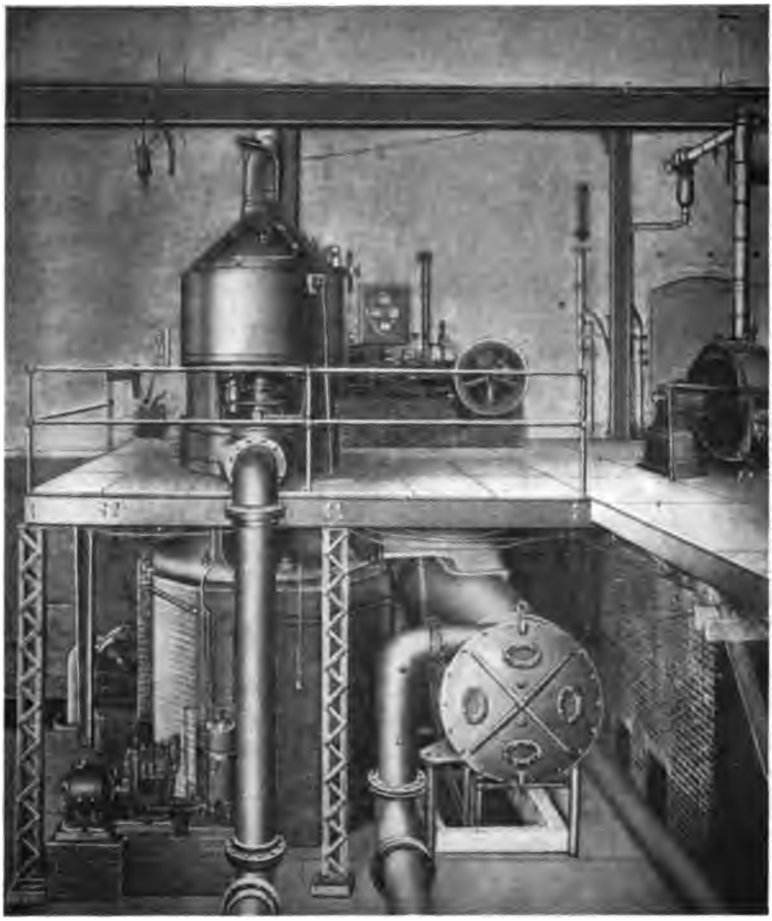


FIG. 137.—500 K.W. 575 Volt Continuous Current Curtis Turbo-Generator (with Separate Condensing Plant in Basement).

(Northern Ohio Traction Co., Akron, O.)

5000 kilowatt units with separate condenser are illustrated in Fig. 387, p. 544.

Areas of Steam Passages.—If a high vacuum is to be attained, large exhaust areas (in proportion to the volumes at low pressures) are necessary, and these areas are tabulated above from dimen-

sioned drawings, kindly supplied by the makers, for steam, atmospheric exhaust, and exhaust to condenser.

No reduction in area per rated kilowatt follows the increase in size of unit with separate condensers. This, for large units, is not unnecessary size of passages, but it has obviously the advantage of giving less reduction in vacuum between the condenser and the turbine.

Peripheral Speed of Vanes.—This is generally about

TABLE L.—SIZES AND TYPES OF CURTIS TURBO-GENERATORS WHICH HAVE BEEN BUILT.

Continuous Current Sets.

Rated K.W.	Speed R.P.M.	Stages.	Condensing or Non-condensing.	Shaft.	Poles.	Volts.	Type.
1¼	5000	1	Non-condensing.	Horizontal.	2	60	Loco Headlight Shunt wound.
15[1]	4000	,,	,,	,,[2]	,,	80	Train Lighting.
,,[1]	,,	,,	,,	,,[2]	,,	125	
25[1]	3600	,,	,,	,,[2]	,,	,,	
75	2400	2	Both	,,	4	,,	
150[1]	2000	2, 3	,,	,,	,,	125 & 250	
,,	1800	4	,,	,,	,,	125	
300	1800	3	,,	,,	,,	250	
,,	,,	4	,,	,,	,,	,,	
,,	2000	3	Condensing.	,,	,,	550	Two Generators one Turbine.
600	1800	,,	,,	,,	,,	,,	
500	,,	2	,,	Vertical.	,,	,,	Cork Trams, Fig. 129.
2000	750		,,	,,		575	*See* p. 212.

1 25 per cent. overload for two hours. Shunt or compound wound.
2 15 lbs. per sq. inch oil pressure supplied by pump through worm gear off turbine shaft.

325 to 400 feet per second (about 100 to 125 metres per second).

Pressure Regulation in the Stages.—In the earlier two-stage machines, second stage, hand operated valves were provided for adjusting the pressure for any load.

While it is desirable to approximately maintain correct pressure relation between the stages at all loads, variation in the pressures can be allowed without materially affecting the economy.

TABLE LI.—*Two-Phase and Three-Phase Sets. 60 and 50 Cycles.*

Rated K.W.	Speed R.P.M.	Cycles per second.	Stages.	Condensing or Non-condensing.	Shaft.	Poles.	Volts.
100[1]	3600	60	3	Condensing.	Horizontal.	2	2,300[2]
500[3]	1800	,,	2	,,	Vertical.	4	,,
,,	,,	,,	4	,,	,,	,,	,,
1000	1200	,,	7	,,	,,	6	,,
1500	900	,,	2	,,	,,	8	,,
,,[4]	,,	,,	4	,,	,,	8	3,500
3000	600	,,	4	,,	,,	12	2,300
5000	514	,,	,,	,,	,,	14	6,900[5]
750	1500	50	3	,,	,,	...	6,600
800	,,	,,	4	,,	,,	4	3,000
1000	1500	,,	3	,,	,,	4	4,000[6]
1500	1000	,,	,,	,,	,,	6	6,600
,,	,,	,,	,,	,,	,,	6	11,000[7]
2000	750	,,	,,	,,	,,	8	2,300
3000	600	,,	,,	,,	,,	10	3,000

1 Overload capacity 25 per cent. for two hours. Oil pressure pump through worm gear off shaft, 15 lbs. per sq. inch.

2 Excitation 5 K.W. at full load.

3 Newport, Rhode Island. This appears to be rated at nearly 0·6 K.W. per moving vane, as the Newport turbines have six rows of revolving vanes, 4 rows of fixed vanes, 2 nozzles, 1395 total number of vanes 3 phases (Emmet at Chicago, 1904).

4 1500 K.W. 8 rows revolving vanes, 4 rows fixed vanes, 4 nozzles.

5 Boston Edison Co. Figs. 388 to 390, also Figs. 386, 387, pp. 543–547.

6 Melbourne.

7 Yorkshire Power Co. Figs. 397, 399. For 2000 K.W. see Figs. 391 to 393, pp. 548–549.

TABLE LII.—*Two-Phase and Three-Phase Sets. 40 and 25 Cycles.*

Rated K.W.	Speed R.P.M.	Cycles per second.	Stages.	Condensing or Non-condensing.	Shaft.	Poles.	Volts.
1500	800	40	2	Condens.	Vertical.	6	2,300
800	1500	25	4	,,	...	2	10,000
1000	,,	,,	,,	,,	,,	,,	6,600
2000	750	,,	,,	,,	,,	4	2,300
,,	,,	,,	,,	,,	,,	,,	6,600
5000	500	,,	2[1]	,,	,,	6	2,300
,,	,,	,,	4	,,	,,	,,	6,600
,,	,,	,,	5	,,	,,	,,	11,000
8000[2]	750	,,	,,	,,	,,	4	6,600

1 Four 5000 K.W. Curtis turbines for Commonwealth Co., Chicago, had two stages 8 rows revolving vanes, 6 rows fixed vanes, 30 valves in two sets of 15 for admission. The cast-iron diaphragm was fitted with hand-operated valves supplying second stage. It was intended to replace these by automatic second stage valves. (Emmet's Chicago Paper, June 1904, Amer. Soc. Mech. Engrs.).

2 Stated as 9000 K.W. twenty-four hour rating, 50 per cent. overload for two hours, in *Elec. World and Engr.*, p. 385, Sept. 2, 1905, for Waterside Station No. 2, New York Edison Co.

If the valves are set to give normal pressure in the first stage at full load, a partial vacuum may exist in the first stage when running on light loads. This reduces the rotation losses due to operating in the rarer medium, and thus counterbalances the losses due to incorrect pressure relations between the stages. In the three- and four-stage turbines the pressure in the first stage is

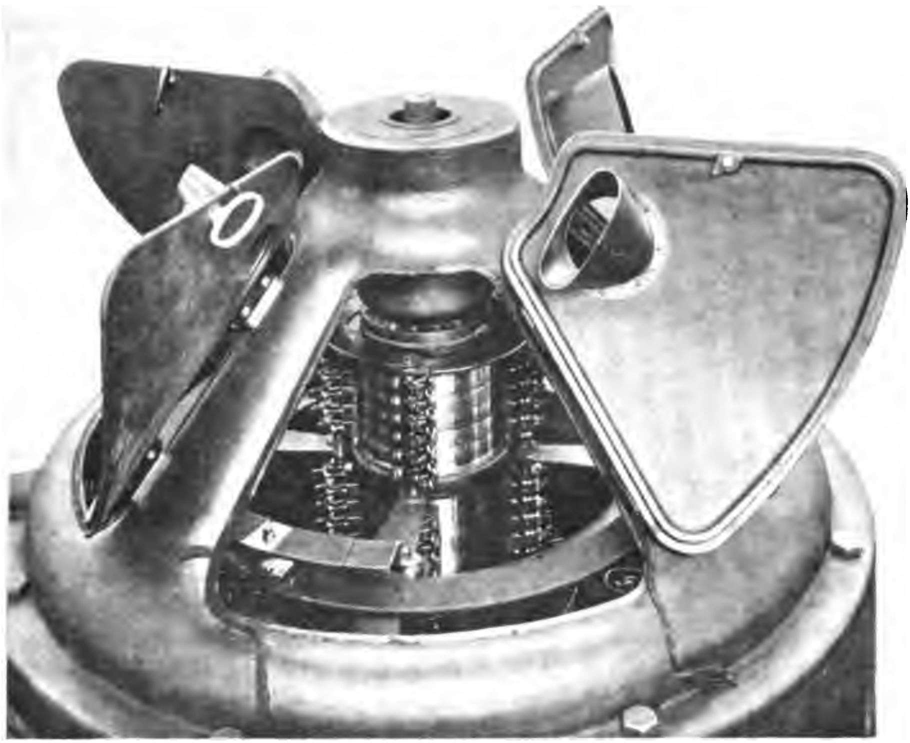


FIG. 138.—Commutator of 4 Pole 500 K.W. 1800 R.p.m. 550 Volt Continuous Current Curtis Turbo-Generator.

controlled by automatic valves which open or close nozzle passages leading to the second stage.

Hand operated valves are provided in the second stage for varying the number of active nozzles, but these are seldom required. If the turbine is called upon to operate, say at high overload, for a long period, it will slightly improve the economy to open more nozzles, thereby lowering the pressure in the stage.

TABLE LIII.—CLEARANCES. MINIMUM CLEARANCES BETWEEN STATIONARY AND MOVING PARTS IN LATEST DESIGNS.

Rated K.W.	Stages.			
	1st.	2nd.	3rd.	4th.
	ins.	ins.	ins.	ins.
500	·04	·04	·04	·05
5000	·08	·08	·09	·12

All the stationary vanes are rigidly fastened to the turbine shell, and the adjustment of the clearance is made by means of the adjusting screw under the footstep.

TABLE LIV.—DIMENSIONS AND WEIGHTS (APPROXIMATE) OF COMBINED TURBINE AND GENERATOR (CONDENSER NOT INCLUDED).

K.W.	Dimensions in Plan.	Height.	Lbs. per K.W.	Lbs.
	ft. in. ft. in.	ft. in.		
500	8 0 × 7 8	14 6		
	7 8 diam.	12 4	100[1]	50,000
800	7 0 × 6 9	16 9¼		
1000	9 5 × 9 2	16 4½		
1500	10 3 × 10 0½	16 6	83[2]	125,000
2000	11 1 × 10 8	17 6	95	190,000
3000	13 6 × 13 0	19 10½	92	275,000
5000	15 3 × 14 10	25 6	76[3]	380,000
"	15 4 × 15 2	27 7		
8000	" "	32 0	88	700,000

[1] Generator 21,000 lbs.; Turbine 26,000 lbs.; Accessories 3000 lbs.
[2] Condenser installed by Yorkshire Power Co. (Fig. 397) adds 38,500 lbs. to this.
[3] Revolving part, 125,000 lbs.; Stationary part, 255,000 lbs.; Generator field, 45,000 lbs.; Generator Armature, 65,000 lbs. (heaviest single part).

TABLE LV.—DIMENSIONS AND WEIGHTS (APPROXIMATE) OF TURBO-GENERATORS, INCLUDING SUBBASE CONDENSERS.

K.W.	Plan.	Height.	Lbs. per K.W.		Total. Lbs.
			Turbo-Generator.	Condenser.	
	ft. in. ft. in.	ft. in.			
750[1]	10 6 × 8 6	16 6	59	42	76,000
1500[2]	11 0 × 10 0	19 6	63	35	147,000

[1] Air pump in plan 40 sq. ft. and weighs 2 tons.
[2] " 50 " " 3 "

Dorchester Unit.—This is a direct-current 2000 kilowatt Curtis General Electric machine, 750 revolutions per minute, 10 poles, 575 volts, and weighs complete 95 lbs. per kilowatt, 190,000 (lbs. total). Height 21 feet, diameter of base 11 feet 2 inches. The guaranteed steam consumption with 180 lbs. steam pressure, 100° F. superheat, and not over 2 inches absolute back pressure in the condenser, is as follows:—

K.W. at the Switchboard.	Lbs. per Hour.
1000	19·6
1500	18·8
2000	18·0
2500	18·4

For the step-bearing water is supplied by either of two steam pumps, delivering 7·5 gallons per minute at 800 lbs. per square inch. For the other bearings oil is supplied by either of two pumps, delivering 0·8 gallons per minute at 35 lbs. pressure.

Brake.—To stop the turbo-generator, a brake bearing on the lower surface of a chilled cast-iron ring is sometimes provided, with the brake shoes set about 0·01 inch below the brake ring.

It is said that the revolving part of the 5000 kilowatt machines in Fisk Street Station of the Commonwealth Electric Co. of Chicago continued to run for four or five hours after the steam had been shut off, if no load was put on the generator to act as a brake.

Manufacturers of Curtis Turbines. — There are four companies engaged in manufacturing this type of machine—the British Thomson-Houston Co. at Rugby, Compagnie Française Thomson-Houston in Paris, Allgemeine Elektricitäts Gesellschaft, Berlin, and the General Electric Company at Schenectady and Lynn, U.S.A. There are a few of these turbines in service in England of 750 and 1500 kilowatts rated capacity. In America there are "in use and under construction" two of 8000 kilowatts, about twenty-four of 5000 kilowatts rated capacity, and eight of 3000 kilowatts rated capacity, and one of 5000 kilowatt was installed as long ago as October 1903, also eighteen of 2000 kilowatts, twenty-four of 1500 kilowatts, and 125 of 500 kilowatts.

At Rugby the following have been constructed:—

Yorkshire Power Co.	3 of 1500 K.W.
Lancashire "	4 " "
Hammersmith Corporation . .	1 " "

County of London E.S. Co. . . .	2 of 1500	K.W.
Leeds City Tramways	2 1000	„
Wimbledon Corporation	1 „	„
Melbourne „	1 „	„
Fulham „	1 750	„
Harrogate „	1 „	„
Rangoon	2 „	„
Messrs Bolckow, Vaughan & Co. .	1 500	„

Steam Consumption.—On steam consumption we have not enough data to make comparisons such as have been made in the

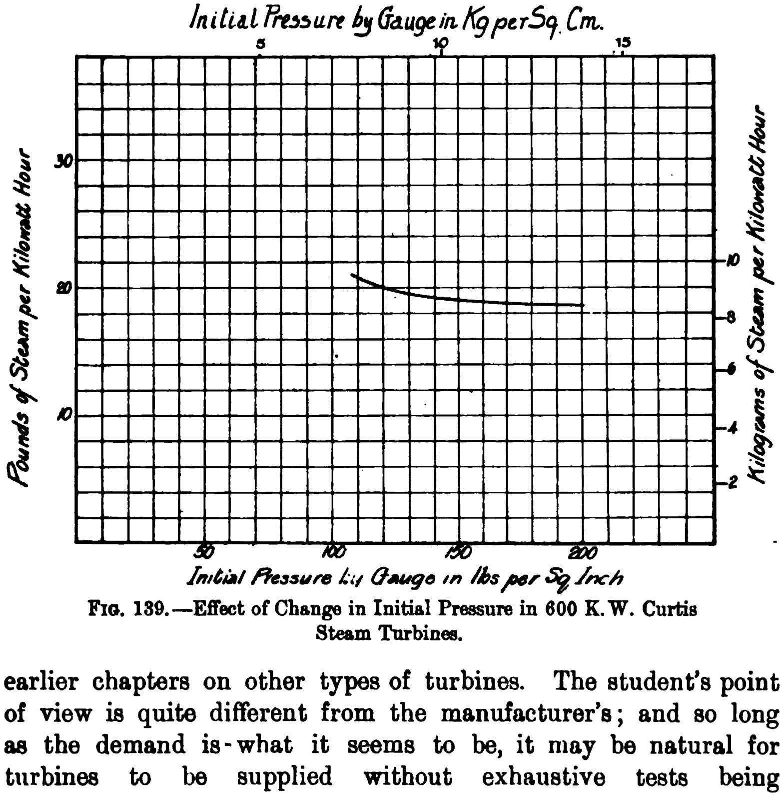
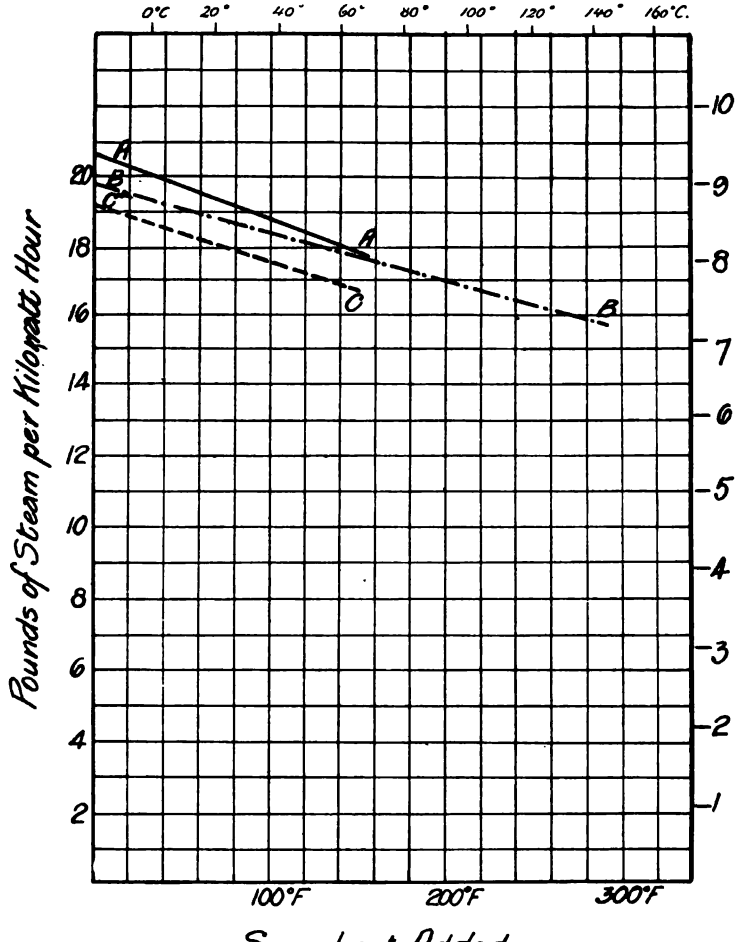


FIG. 139.—Effect of Change in Initial Pressure in 600 K.W. Curtis Steam Turbines.

earlier chapters on other types of turbines. The student's point of view is quite different from the manufacturer's; and so long as the demand is what it seems to be, it may be natural for turbines to be supplied without exhaustive tests being published.

The English and the American makers have kindly given permission for their tests to be reproduced showing the effects on steam consumption of changes in initial pressure in a 600 kilowatt Curtis steam turbine (Fig. 139, above), the effect of changes in vacuum in a 500 kilowatt and in a 600 kilowatt unit (Fig. 140, p. 214), and the effect of varying the superheat (Fig. 141, p. 215).

500-Kilowatt Tests.—An alternating current 500 kilowatt unit was installed at Rugby over two years ago, and continuous



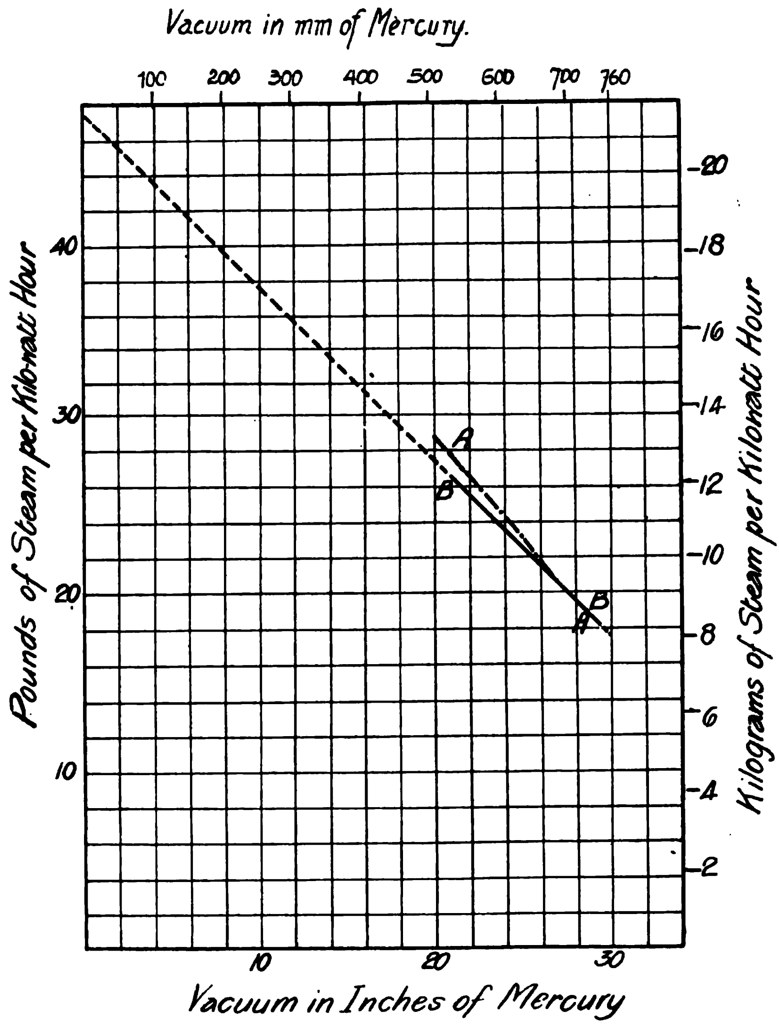
A = 150 lbs. per Sq. In. 28½ in. Vacuum 500 K.W., F. Samuelson, *Engineering*, p. 183, Feb. 5, 1905.
B = Do. do. 500 K.W. *Proceedings Engineers Club*, Philadelphia, April 1904.
C = 140 lbs. do. do. 600 K.W., General Electric Co. of New York, May 1903.

FIG. 140.—Curtis Turbines: Effect of Superheat on Steam Consumption.

current units of same capacity at Cork and Rugby, Figs. 142, 143, and Table LVI.

The Newport plant contains three 500 kilowatt Curtis turbo-

alternators, 3 phase, 60 cycles, 4 poles, 1800 revolutions per minute, coupled to one Wheeler surface condenser, with 20 horse-



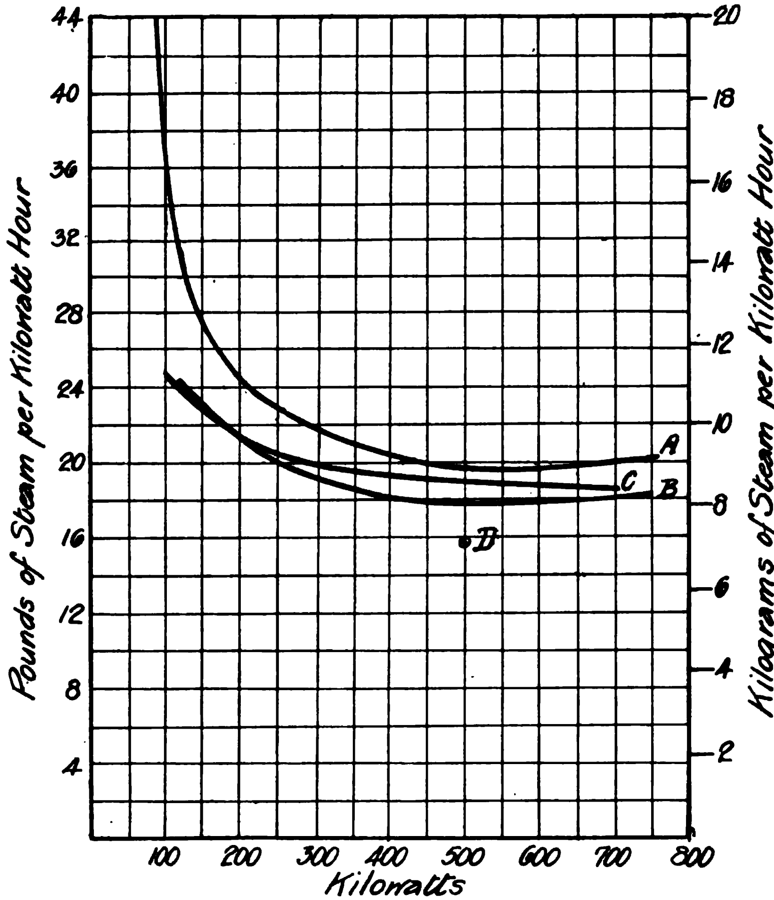
Curve A = 150 lbs. per Sq. In. 115° F. F. Samuelson, in *Engineering*, p. 183, Feb. 5, 1904.

,, B = 140 lbs. do. do. General Electric Co. of New York, p. 273–8, May 1903.

FIG. 141.—Effect of Varying Vacuum on 500 and 600 K.W. Curtis Steam Turbines.

power circulating pump motor, 15 horse-power motor, driving Edward's air pump, operating with vacuum between 28½ and 29 inches. The motor-driven oil pump for bearings has a cylinder 1

inch in diameter by 3 inches stroke, and has an input of 3 amps. 85 volts. Oil is used for footstep and other bearings, and 9 gallons is the consumption per month for each unit.



A = 160 lbs. per Sq. In. (11·2 Kgs.) Zero Superheat, 95 per cent. Vacuum.
B = ,, ,, 125/150° F. ,, ,,
C = 165 ,, (11·5 Kgs.) 115° F. 64° C. ,, ,,
D = ,, ,, 290° F. (166° C.) ,, ,,

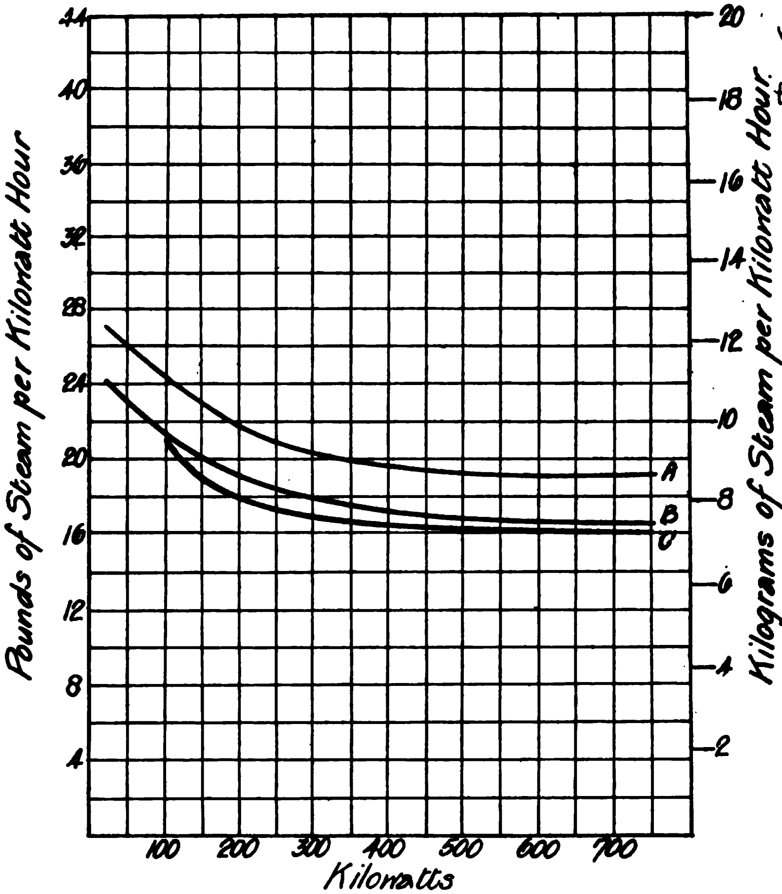
FIG. 142.—Steam Consumption of 500 K.W. Curtis Turbine Vacuum Constant at 95 per cent.

The circulating water, when taken in at 36° F. in winter and 72° F. in summer, is discharged at 55° F. in winter and 90° F. in summer.

One 30 kilowatt, 125 volt generator, driven by a 305 revolu-

tions per minute steam engine, having cylinder of 11 inches diameter by 8 inches stroke, and a generator of 35 kilowatt, 720 revolutions per minute, driven by an induction motor, supply the exciting current.

Mr F. Samuelson's tests on an alternating 500 kilowatt unit at



A = 155 lbs. per Sq. In. Abs. (10·9 Kgs.) Zero Superheat 95 per cent. Vacuum.
B = ,, ,, ,, 150° F. ,, (83° C.) ,,
C = 215 ,, ,, (15·1 Kgs.) 150° F. ,, (83° C.) ,,

FIG. 143.—Steam Consumption of a 600 K.W. Curtis Turbine at Various Loads, Vacuum Constant at 95 per cent.

Rugby were presented to the Rugby Engineering Society, November 1903. Mr Chas. Merz, consulting engineer to Cork Tramways, published some tests on a 500 kilowatt continuous current set installed at Cork.

TABLE LVI.—500 K.W. CURTIS TURBINE TESTS.

Steam Consumption in Lbs. per K.W.H.

Tested at	Newport.				Rugby.	Cork.						Oshkosh Gas Co.		
Column Number	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14
Date of Test	Jan. 15 1904	Jan. 26 1904	..	..	1903	Nov. 1904	..	..	..	..	corrected results	..	..	..
Voltage	2300	..	..	..	..	550	..	..	..	..	..	..	..	..
Cycles	60	..	..	..	..	c.c.	..	..	..	..	..	..	..	..
Speed R.p.m.	1845	..	..	..	1800	1835	1820	1822	1820	1800	..	..	..	..
Rated Output of unit K.W.	500	..	.	.	500	500	..	..	..	..	..	..	..	..
Duration of Test, hours	12	15	..		..	1·5	1·5	1·5	1·5	under 1	..	12	..	..
Average Load K.W.	421	253	..	..	..	.	..	..	..	..	..	262·7 real K.W.	226·5	..
Max. and min. Load K.W.	..	114/333	.		..	126	250	384	512	613	..	144 to 352 averaging 1 hour for each load	..	..
Load by polyphase meter (Newport)	406	..		..	..	..	..	..	.	..	..	..	..	..
Difference (Newport) is load on auxiliaries	15	..	..	..	..	..	..	..	..	..	..	..	..	..
Power factor average, min. and max		..	..	..	..	..	..	..	.	..	..	77·7% average 62·4 min. 86·8 max.	..	..
Pressure, lbs. per sq. inch	about 145	..	..	..	150	155	155	153	153	151	*155*	..	..	..
Superheat	nil	..	150°	289°	115° F.	51°	50°	70°	104°	124°	*115°*	..	..	..
Vacuum at Turbine	about 95%	..	..	..	28·5″	28·8″	28·6	27·8	26·9	26·2	*26·6″*	..	..	..
Barometer	..	..	..	..	30″	30·16″	30·16	30·16	30·16	30·16	*30·16*	..	..	..

Lbs. of Steam per K.W. hour:														
At 50% overload	20·22	..	..	..	18 4	..	..	..	..	..	..	.	..	..
,, 25% ,,	..	..	..	..	..	..	..	..	..	21	*18*	..	..	non-inductive load 20·19
,, full load	19·78	..	17·79	15·91	18 75	..	..	..	20·6	..	*18*	..	..	20·54
,, ¾ load	20·69	..	..	..	19·4	..	..	20·9	..	..	*19·2*	..	..	..
,, ½ ,,	21·38	22·38	..	..	20·5	..	22·6	..	..	..	*23*	..	..	24·29
,, ¼ ,,	27·85	..	..	..	22·3	24·9	..	..	..	..	*24*	..	..	..
,, no load	14% of full load	..	..	..	not stated	..	..	..	..	..	..	*262·7 K.W*	*226·5 K.W.*	..
,, average load	..	..	..	..	..	..	..	..	..	..	..	23·9 lbs. condensing	58 lbs. non-condensing	..
,, ,, ,, including all auxiliaries and boiler feed pump	.	..	..	..	..	..	..	..	..	..	..	31·7	..	..
Coal, lbs. per K.W. hour	2·67	2·54	..	..	..	..	..	..	..	..	..	5·43	..	..
Calorific value	..	not stated	..	..	..	..	..	..	..	..	..	..	..	..
Price per ton	..	16/9	..	..	.	..	..	..	..	..	..	..	..	..
Evaporation per lb. of coal	..	..	..	..	..	..	..	..	..	..	..	6·23	..	..
Speed Regulation:														
No load to full load	0·8%	..	..	..	..	..	..	..	..	..	..	..	..	..
Momentary	2·1%	..	..	..	..	..	..	..	..	..	..	..	..	..
Voltage Regulation	10%	..	..	..	..	..	..	..	..	..	..	..	..	..
Temperature rise:														
8 hours 32% overload	38° C.	..	..	.	..	..	..	..	..	..	..	..	..	..
2 ,, 54% ,,	38° C.	..	..	..	..	..	..	..	..	..	..	..	..	..
Air Pumps used K.W.	..	..	..	..	1·8	.	..	..	..	..	..	..	..	..
Circulating Pumps used K.W.	..	..	..	..	7·1	.	..	..	..	..	..	..	..	..
Condenser Cooling Surface per rated K.W.	..	..	..	..	3 sq. ft.	..	..	..	..	..	..	4 sq. ft.	..	..
Test by	..	..	..	..	Mr F. Samuelson.	Mr Chas.		H. Merz.		..	..	Mr Otto E. Osthoff.		..
Data from	Emmet, before Engineers' Club, Philadelphia. *Proceedings*, vol. xxi. pp. 198–209, April 1904.				*Engineering* Nov. 5, 1903	*The Electrical Times*, Nov. 17, 1904. Vacuum at condenser 2 inches better than at turbine, showing insufficient area of condenser inlet.						*Elec. World and Engr.*, p. 875, May 13, 1905.		

A 500 kilowatt Curtis turbo-generator, installed by the Oshkosh Gas Light Co., Wisconsin, U.S.A., in December 1904, was tested by Mr Otto E. Osthoff, of Messrs H. M. Byllesby & Co., consulting engineers, on what he called commercial runs, averaging one hour for each load. The generator is wound for 3 phases, 60 cycles, 2300 volts; the condenser, by Worthington, has 2000 square feet cooling surface. The footstep-bearing is supplied with water at 300 lbs. per square inch from either of two Worthington double-acting pumps, which also supply an accumulator as a reserve in case the pump fails. The two upper bearings are lubricated with oil by gravity.

TABLE LVII.—TESTS ON 2000 K.W. CURTIS STEAM TURBINES.

Test.		Pounds of Steam per K.W.H.	Pressure. Lbs. per sq. in.	Inches of Mercury. Vacuum.	Absolute Back Pressure.	Super-heat F°.	Revolu-tions per minute.	Reference.[1]
Load K.W.	Duration. Minutes.							
Zero	80	(1510 lbs. per hour)	154 gauge	..	1·85	156	..	June 1905.
Zero	Field excited	(1530 lbs. per hour)	165 ,,	28	..	157	932	May 3, 1905.
555	60	18·09	155	..	1·45	204	..	June 1905.
560	..	17·86	163 gauge	28·4	..	210	930	May 3, 1905.
636	..	20·94	148	28·1	..	207	..	Test No. 5.
637	..	20·1	150 gauge	28·2	..	215	750	Mar. 12, 1904.
1000	..	16·38	177	28·9	..	234	..	Test No. 4.
1000	..	16·3	160 gauge	28·9	..	242	750	Mar. 12, 1904.
1040	..	15·87	167 ,,	28·38	..	190	928	May 3, 1905.
1066	..	16·33	171 ,,	28·48	..	105	928	May 3, 1905.
1067	55	16·31	170	..	1·40	120	..	June 1905.
1740	..	15·3	155 gauge	28·7	..	202	750	Mar. 11, 1904.
1750	..	14·2	140 ,,	28·5	..	200	760	Feb. 23, 1904.
1970	..	15·12	162 ,,	28·15	..	210	918	Apr. 27, 1905.
1970	..	16·20	165 ,,	28·21	..	105	918	May 2, 1905.
2000	..	15·3	160 ,,	28·8	..	242	750	Mar. 12, 1904.
2005	..	15·8	169 ,,	28·37	..	125	918	May 3, 1905.
2016	..	15·24	165	28·7	..	252	..	Test No. 3.
2024	..	15·02	166 gauge	..	1·49	207	..	June 1905.
2208	..	15·46	176	28·5	..	193	..	Test No. 2.
2210	..	15·2	160 gauge	28·5	..	212	750	Mar. 11, 1904.
2400	..	13·5	156 ,,	28·5	..	239	760	Feb. 25, 1904.
2747	..	16·37	174	(?)	..	195	..	Test No. 1B.
2754	..	15·57	174	28·4	..	221	..	Test No. 1A.
2760	..	16·2	160 gauge	28·35	..	192	750	Mar. 11, 1904.

[1] The 1905 tests were made on a 4-stage turbine of essentially the same design as machines built two years earlier, but run at higher vane or bucket speed, and with improved vanes and nozzles.

The numbered tests as stated above were on a 3-stage turbine.

The numbered tests indicated by × in Fig. 144 are taken from a summary, p. 43, *Proceedings of National Electric Light Association*, Boston, Mass., May 1904, "Report of the Committee for the Investigation of the Steam Turbine," W. C. L. Eglin, F. Sargent, and A. C. Dunham.

The 1904 tests indicated by ⊖ in Fig. 144 are taken from p. 204, *Proceedings of Engineers' Club of Philadelphia*, April 1904, W. L. R. Emmet.

The 1905 tests indicated by □ in Fig. 144 are from p. 17, *Proceedings National Electric Light Association*, Denver, June 11, 1905, Augustus H. Kruesi. The June 1905 tests indicated by △ in Fig. 144 are by Messrs Sargent and Ferguson, *St. Ry. Jour.*, p. 150, July 22, 1905.

Non-condensing.—"At rated load non-condensing, about twice as great as it would be with good vacuum."—*W. L. R. Emmet.* Compare columns 12/13 Table LVI.

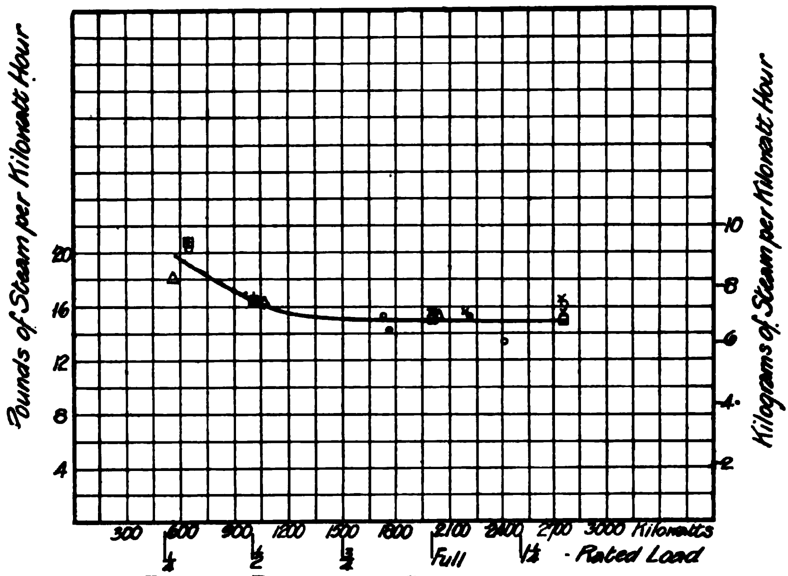


FIG. 144.—Tests on 2000 K.W. Curtis Steam Turbines.
(*See Table LVII. for conditions.*)

TABLE LVIII.—2000 K.W. TEST IN EACH OF THREE STAGES.

Test Number	1A.	1B.	2.	3.	4.	5.
Load, K.W.	2754	2747	2203	2016	1000	636
Steam, lbs. per K.W.H.	15·57	16·37	15·46	15·24	16·38	20·94
Pressures, lbs. per sq. in.:						
Throttle	174	174	176	165	177	148
1st stage	54·5	...	46·5	48·8	26·5	12
2nd "	23·3	...	15·	13·4	7·1	5·4
3rd "	4·4	...	4·2	3·7	2·9	2·2
Condenser	·8	...	·72	·64	·54	·94
Temperatures, °F.:						
Throttle R	591	566	565	618	606	565
" L	591	566	554	433	426	418
2nd stage R	379	...	370	373	371	320
" " L	327	...	317	322	315	262
3rd "	269	...	266	259	141	215
Condenser	105	...	103	93	124	115
Superheat, °F.:						
Throttle R	221	...	193	252	234	207
" L	221	...	182	67	54	60
2nd stage R	138	...	157	166	193	155
" " L	86	...	104	116	137	97
3rd stage	112	...	111	113	72	85
Condenser	10	...	7	5	42	15

The summary of numbered tests referred to above gives the following interesting figures on each of the three stages in the 2000 kilowatt unit tested. These tests were probably made at the makers' works, and may have been on the same machine as those reported under dates February and March 1904 above.

TABLE LIX.—POWER FOR AUXILIARIES.

Rated Size of Unit.	Number of Units.	Rating of Motors. Air Pump.	Circulating.	Step Bearing.	Other Bearings.	Place.
500[1]	3	15 H.P.	20 H.P.	...	...	Newport, R.I.
	1	Input 1·8 K.W.	Input 7·1 K.W.	Input 0·3 K.W.	...	Rugby.[2]
750	1	12 H.P.	35 H.P	1·5 H.P.	...	Fulham, London.
1500	3	9 K.W.	18 K.W.	...	...	Schenectady.
2000	5	...	...	...	...	Quincy.
"	1	See Fig. 145	...	...	...	St Louis Exhibition.
5000	2	Input 1800 lbs. steam per hour	Input 5400 lbs. steam per hour	...	...	Boston Edison Co.
5000	...	"All auxiliaries driven by a single cylinder Corliss engine, which delivers 70 I.H.P. when 5000 K.W. unit is running at full load."		...	..	Chicago Edison Co.

[1] Emmet, *Proceedings Engrs. Club, Philadelphia*, xxi. p. 208, April 1904.
[2] F. Samuelson, Rugby Engineering Society, Nov. 5, 1903. See also p. 454 for data on other plants, and p. 430 for input to auxiliaries.

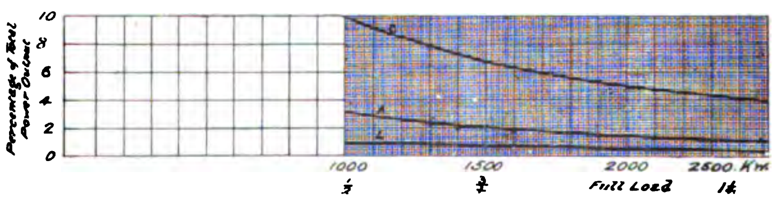


FIG. 145.—Power used by Auxiliaries to 2000 K.W. Curtis Turbine.

C = *Circulating Pump.* A = *Air Pump.* L = *Lift Pump from hot well.*

"Casual Observations" of Power Output from Stepdown Transformers supplying Constant Speed Motors at St Louis Exhibition (assuming the power constant for all loads). *From Report Am. St. Ry. Assoc.*, Oct. 1904, p. 184, by Mr J. R. Bibbins.

Other Illustrations.—In the chapter on Examples of Turbine Plants several Curtis Installations are listed and illustrated.

Fig. 146 shows the revolving part of a vertical four-stage turbine from a photograph taken with the shaft in a horizontal position, thus giving incorrect light-and-shade effect. Each stage has two rings of revolving blades.

Fig. 147 is an outline to scale of the 750 K.W. Curtis set at Harrogate, with subbase condenser and motor-driven three-throw pump. Fig. 402, p. 558, shows the 750 K.W. set at Fulham.

The alternating set on which the tests in Table LVI., column 5, were made, is illustrated in Fig. 148.

Low-pressure Curtis Turbine.—A low-pressure 800 kilo-

FIG. 146.—Revolving Part of a Four-Stage Curtis Turbine.

watt set at the plant of the Philadelphia Rapid Transit Company at Mt. Vernon and 13th Streets uses the exhaust from a plant (previously non-condensing) of four Corliss type engines, totaling 8000 K.W., and exhausts into an Alberger surface condenser which is stated (*Street Ry. Journal*, p. 1102, Dec. 23, 1905) to have 8000 square feet of surface.

This appears to be a four-stage turbine, with four rings of moving vanes or blades.

It is claimed that from the exhaust of one of the Corliss sets (rated 1500 K.W.) with 1150 K.W. load, 750 K.W. is developed. Of this, 85 K.W. is expended on driving auxiliaries which include

the input to a motor-driven lift pump (motor rated at 120 horsepower) for cooling towers (22 feet diameter, 41 feet high).

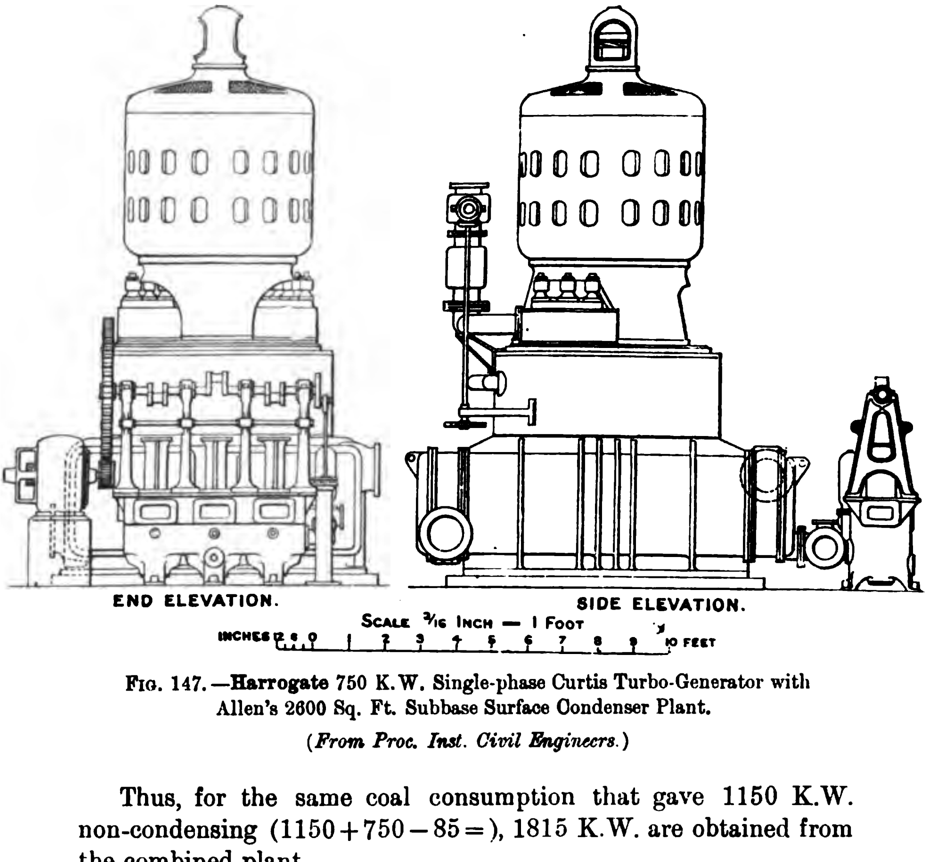


FIG. 147.—**Harrogate** 750 K.W. Single-phase Curtis Turbo-Generator with Allen's 2600 Sq. Ft. Subbase Surface Condenser Plant.

(*From Proc. Inst. Civil Engineers.*)

Thus, for the same coal consumption that gave 1150 K.W. non-condensing $(1150+750-85=)$, 1815 K.W. are obtained from the combined plant.

The guarantees for the low-pressure turbine are:—

With Absolute Admission Pressure: lbs. per sq. in.	14·7	14·7
Wetness Factor	zero	zero
Vacuum: Abs. Back Pressure: lbs. per sq. in. .	1	2
Steam Consumption per K.W.H.:		
Full Load	36 lbs.	45
Half „	40 „	50

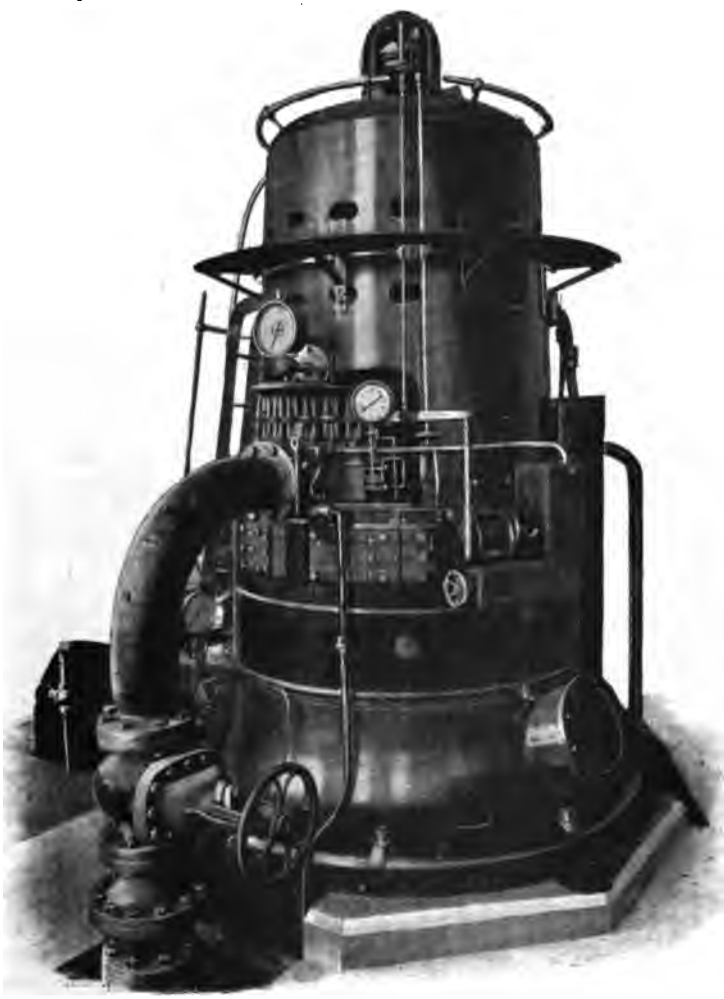


FIG. 148.—**Rugby** Curtis 500 K W. Turbo-Generator.

CHAPTER VI

RATEAU STEAM TURBINE

PROFESSOR A. RATEAU, of the École Supérieure des Mines, Paris, has brought to bear upon the question of steam turbine design his

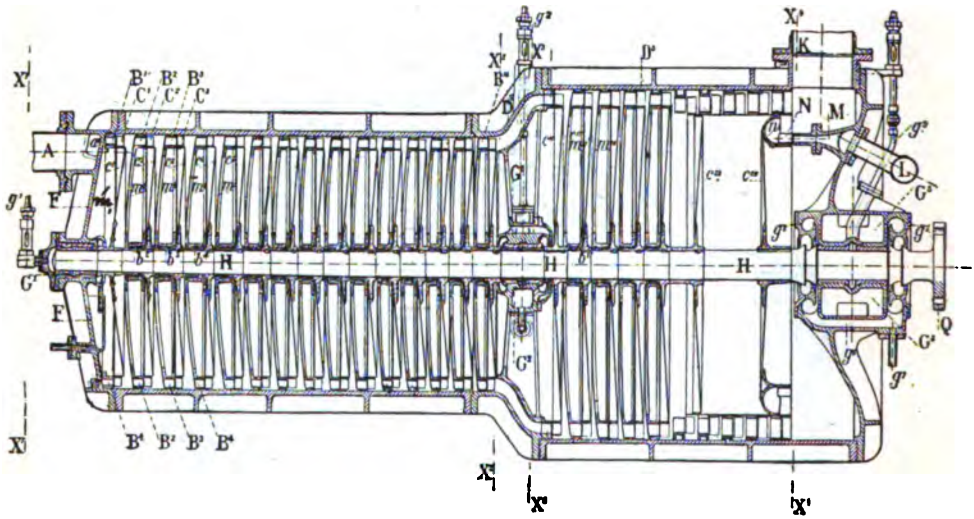


FIG. 149.—Rateau Turbine, Elevation in Section.
(From *The Electrical Review.*)

A, steam admission.
B1, B2, etc., guide vanes as in periphery of fig. 152.
C1, C2, etc., revolving vanes.
See note, p. 235.
*m*1, *m*2, etc., diaphragms carrying B1, B2, etc.
K, exhaust to condenser.
L, steam admission to N.
N, reverse vanes.

highly technical knowledge, and has attained excellent results in steam economy. He has devoted attention to the problem of saving some of the energy which was usually wasted in hoisting plants and steel works, in steam exhausted into the atmosphere, by

storing the heat which comes from the reciprocating engine or hammer intermittently, in a regenerative heat accumulator which gives up the regular supply of steam necessary for a low-pressure steam turbine to develop power. Professor Rateau has very fully described his work and results before various bodies of engineers and others, in England and elsewhere.[1]

The Rateau Steam Turbine.—To turn to the turbine itself, Fig. 149 shows a section of a Rateau turbine having fifteen pressure stages of the smaller diameter and ten of the larger

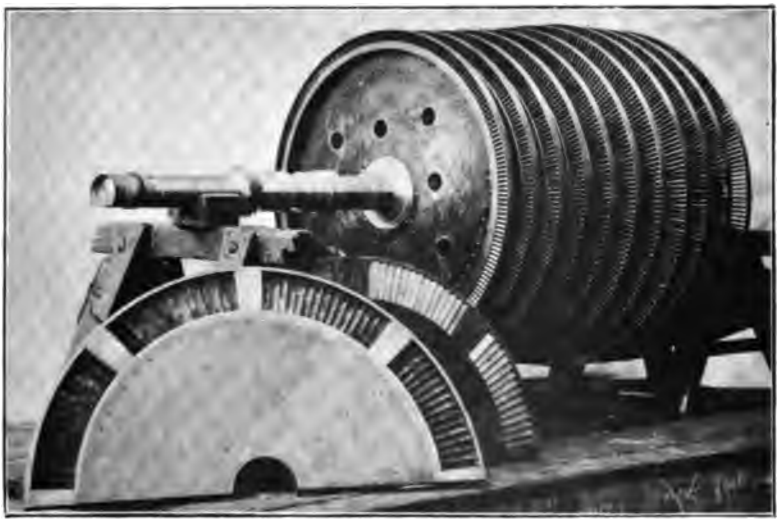


FIG. 150.—Revolving Part of Rateau Turbine by Messrs Fraser & Chalmers. Supplied to the Steel Co. of Scotland.

diameter, making a total of twenty-five. In addition, there are special vanes for reversing at N, fed by special steam pipe L, exhausting into the main condenser through pipe K.

Revolving Vanes or Blades.—Thin plates, flanged for support on the axle, and flanged around periphery, and slightly coned, are used to support the revolving vanes in the Rateau turbine, Fig. 150. The vanes or blades are pressed sheet, flanged and riveted to the drum (with a single rivet to each blade), the flange of large vanes being split. They are kept thin to reduce their weight. The outer ends are put through and riveted over on a nickel steel shroud. 30 to 35 per cent. nickel steel is used

[1] Refer to Bibliography at end of this book.

for the vanes. The flange is filed to fit the bend in the next vane, and thus acts also as a distance piece (see Fig. 151).

Each[1] revolving wheel in a Rateau turbine is placed between two "diaphragms," illustrated and described below. That is, each revolving wheel is in a cell or chamber in which the pressure is practically uniform. This led Professor Rateau to name his design "multicellular."

That revolving vanes of the construction used in Rateau turbines give satisfactory service is evidence that they are not subjected to much difference of pressure on the two sides of any

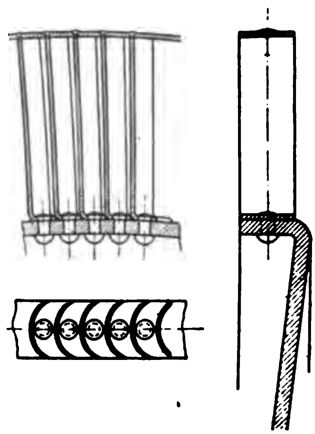


FIG. 151.—Vanes or Blades of Rateau Turbine. (Messrs Fraser & Chalmers.)

one row. This, incidentally, shows that the tendency for steam to leak past the vanes is small.

Pressure Steps.—There are thus as many pressure steps or "stages" as there are revolving wheels,—these successive expansions of the steam taking place in passages through the diaphragms, which increase in cross section from the higher pressure side to the lower.[2]

[1] Professor Rateau, in his paper read at Chicago Meeting of American Society of Mechanical Engineers, June 1904, on "Different Applications of Steam Turbines," p. 7, reiterated his opinion that considerations of steam economy reduce this number of rows of vanes in each stage to one. This differs from the practice of some other makers.

[2] **Difference between Impulse and Reaction Turbines.**—In Professor Rateau's reply to the discussion on his paper on "Steam Turbines" before the Conference of the Institution of Civil Engineers, he said, "The Hon. C. A. Parsons has said that there is no essential difference between impulse and reaction turbines, but it is quite certain that they resemble each other, both having

Diaphragms.—The fixed diaphragms are made, in small sizes, of one casting. In larger sizes a stronger construction is provided. A number of arms join the rim to the hub, and the spaces between the arms are covered on each side of the diaphragm with planished sheet steel.

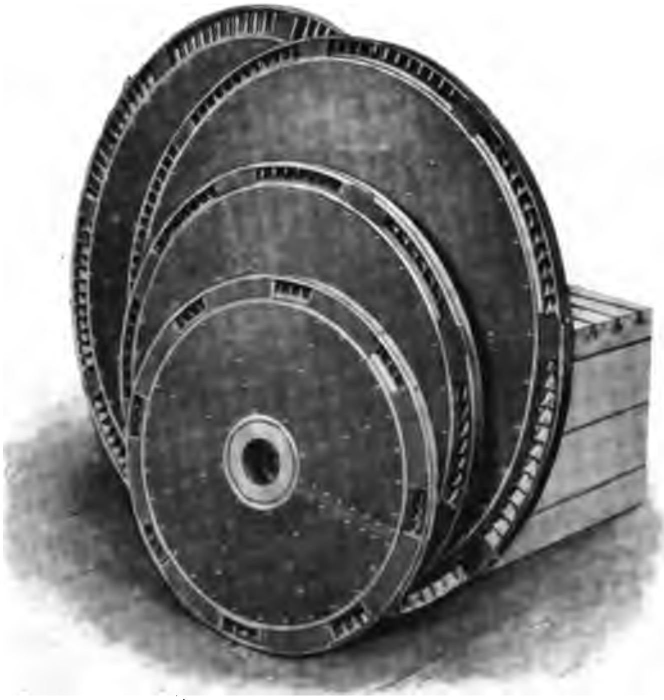


FIG. 152.—Diaphragms of Rateau Turbine.
(From *Electrical Review.*)

Fig. 152 shows a group of diaphragms, and the number of fixed "distributor guide blades" (expanding nozzles), through the first is

rotary wheels and guide blades. There are, however, essential differences between the two, and it is only necessary to open a treatise on hydraulic engines to see that hydraulic engineers attach great importance to the distinction between the two types." Professor Rateau had not sufficient time to develop the reasons for the distinction, but stated that the speed triangle at the entrance to the wheel was very different in the one case from what it was in the other. Fig. 155 shows the speed triangle and the shape of the vanes of his impulse turbine, and Fig. 154 those for a reaction turbine (the latter in the Jonval type).

"As the steam-turbines revolve generally too fast for the work they have to perform, means have to be taken to reduce the speed, and one of them is to cause the turbine to work by impulse, and not by reaction."

small, and this number increases as the position of the diaphragm on the shaft approaches the exhaust end of the turbine. The complete circumference is thus occupied in the last wheels.

The path of any particle of steam through the turbine will

FIG. 153.—Rateau Turbine with Cover removed (3 bearings, 1 internal). (From *The Electrical Review*. See note, p. 235.)

obviously be a helix; it is therefore arranged that these fixed guide blades shall be set along that path.

The diaphragms are fixed in grooves in the inside of the turbine casing. From Fig. 153 it will be seen that the case is divided on the horizontal diameter.

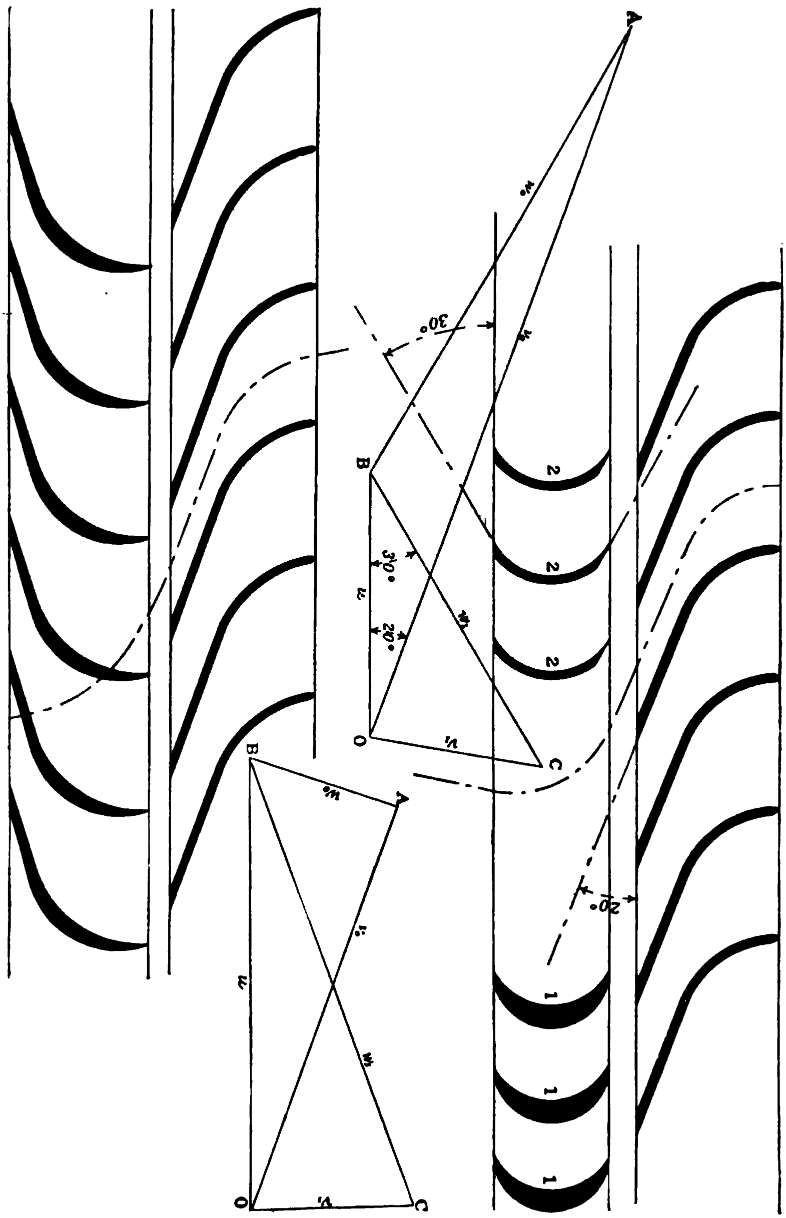


FIG. 154.—Reaction Turbine, Jonval Type.

FIG. 155.—Impulse Turbine.

FIGS. 154 and 155.—Speed Triangles and Shapes of Vanes. (From *Proc. Inst. Mech. Engrs.*)

Shaft.—The shafts are made of nickel steel, and are stepped to facilitate the placing of the revolving wheels.

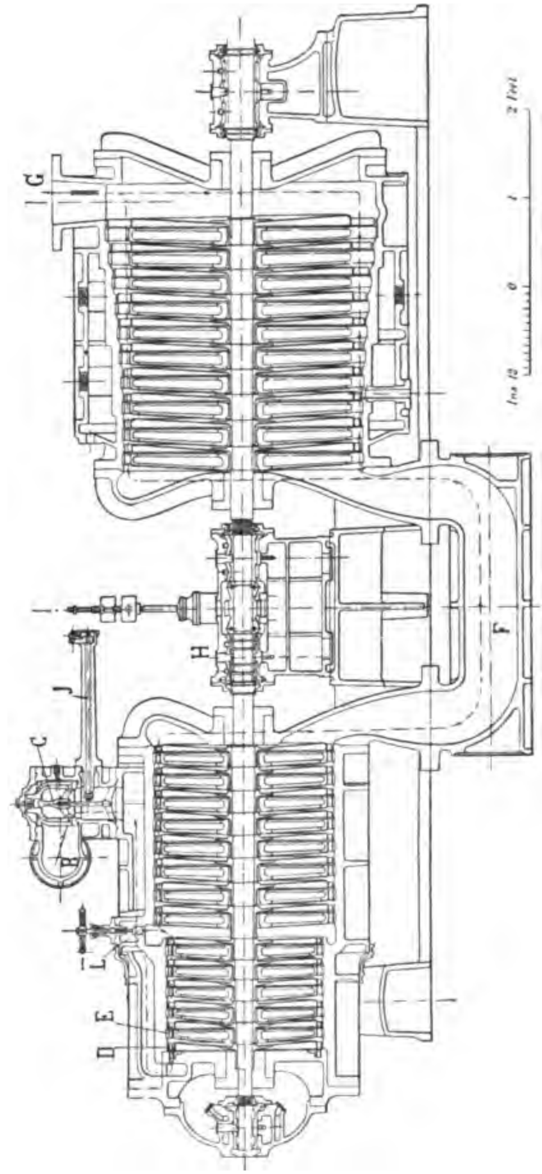


FIG. 157.—Rateau Steam Turbine with Separate Cylinders and Intermediate Bearing, at Peñarroya, Spain.
370 K.W., 2400 R.p.m.; overall length 13 ft. 2 in., width 4 ft. 3 in., height above floor 4 ft. 8 in., below floor 1 ft. 2 in.
24 revolving wheels, smallest 1 ft. 9 in. diameter, largest 3 ft.
2 pole 240 volt generator.
Installed with a Rateau Ejector Condenser.

The shaft runs through these diaphragms in antifriction metal bushes.[1] The leakage area around the shafts is thus a small annulus.

[1] Professor Rateau, as reported, *Engineering*, July 17, 1903, p. 105, stated that he works to 0·2 millimetre play, but he added that the shaft makes its

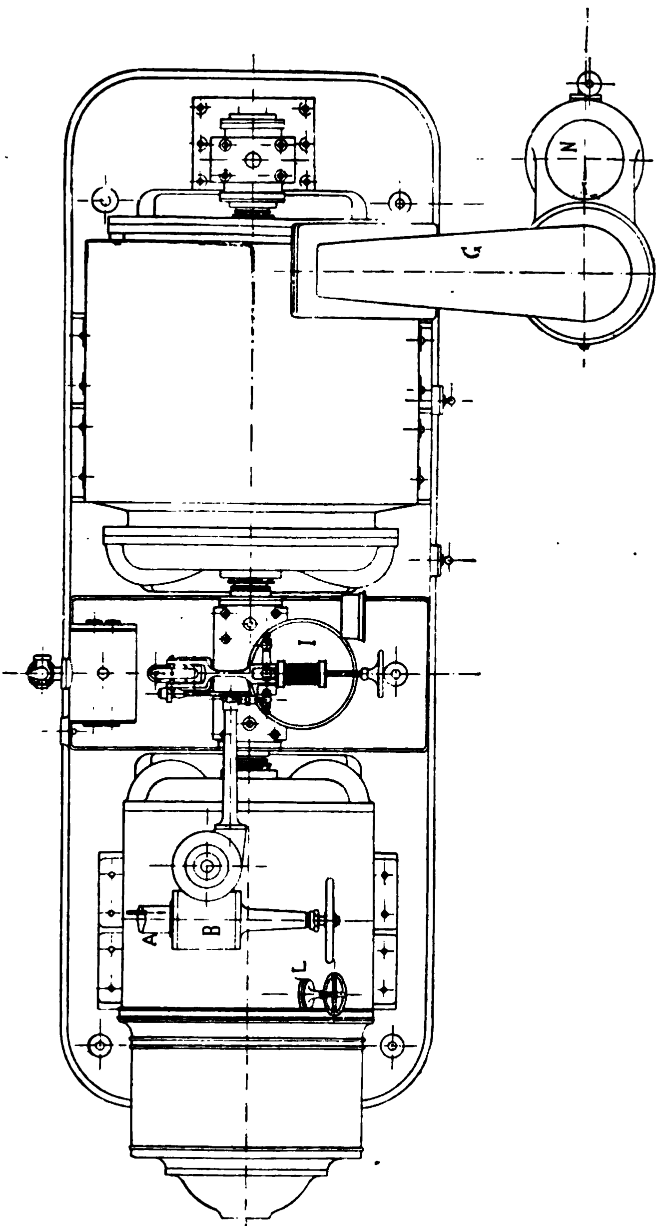


Fig. 157.—Plan.

own play when 0·2 mm. (·008 in.) is insufficient. In his Chicago 1904 paper, "Different Applications of Steam Turbines," p. 13, he stated the loss by leakage and by friction in the bearings as 1½ per cent. of the normal power in a 1500 B.H.P. 1500 R.p.m. multicellular turbine, and the loss due to friction of the wheels upon the steam as 2½ per cent. more,—4 per cent. total.

Speed Control.—The speed of the Rateau turbine at Bruay can be varied by hand regulation of a spring between 1500 and 1800 revolutions per minute (*i.e.* about 10 per cent. either way from the mean speed). In other cases the speed control amounts to 15 to 20 per cent. either way.

Expanding Nozzle.—Dr A. Stodola pointed out that violent acoustic vibrations, which he should always avoid, are set up by using too short nozzles, *i.e.* by allowing the steam to leave the nozzle at a slight over-pressure, which, according to Professor Rateau's tests, "gave only very slight decrease in pressure upon the moving vanes."

Governor and Compensator.—The general arrangement of the governor and compensator that Messrs Fraser & Chalmers employ on turbines is shown on Fig. 156. The governor is driven from the turbine shaft by worm gearing as shown on drawing. The centrifugal force of the masses is in part balanced by the transverse springs which are applied directly to the masses; an exterior regulating spring S is applied to complete the balancing.

The movements of the masses are transmitted to the governor lever by a spindle, the top part of which is a tee on which press the levers of the governor balls. The articulations of the masses and of the transversal springs and of the central spindle are made on point or knife edges. Ball bearings are provided for the vertical spindle. The employment of knife edges and ball bearings for the moving parts reduce the friction of the governor to a small value.

The governor is completed by a compensator, the pinions of which are worked by worm gearing off the governor shaft. By the aid of the compensator the speed of turbine remains constant under a variable load. When a variation of speed takes place the governor acts on the throttle valve, causing it to take a position suitable to the change of load, but with a speed slightly different to that which it had before the variation. The rod is shifted and one of the feathers which it carries is seized by one or other of the toothed pinions, turning it in one direction or the other, increasing or diminishing its length by the nut, and bringing back the governor lever to its mean position. Governing is now re-established, the throttle valve occupying a position suitable to the new load. With the compensator the same speed is maintained with all loads.

Regulator Valve.—The stop valve and governor throttle valve consist of ordinary stop valve operated by hand and double-beat balanced throttling valve controlled by governor.

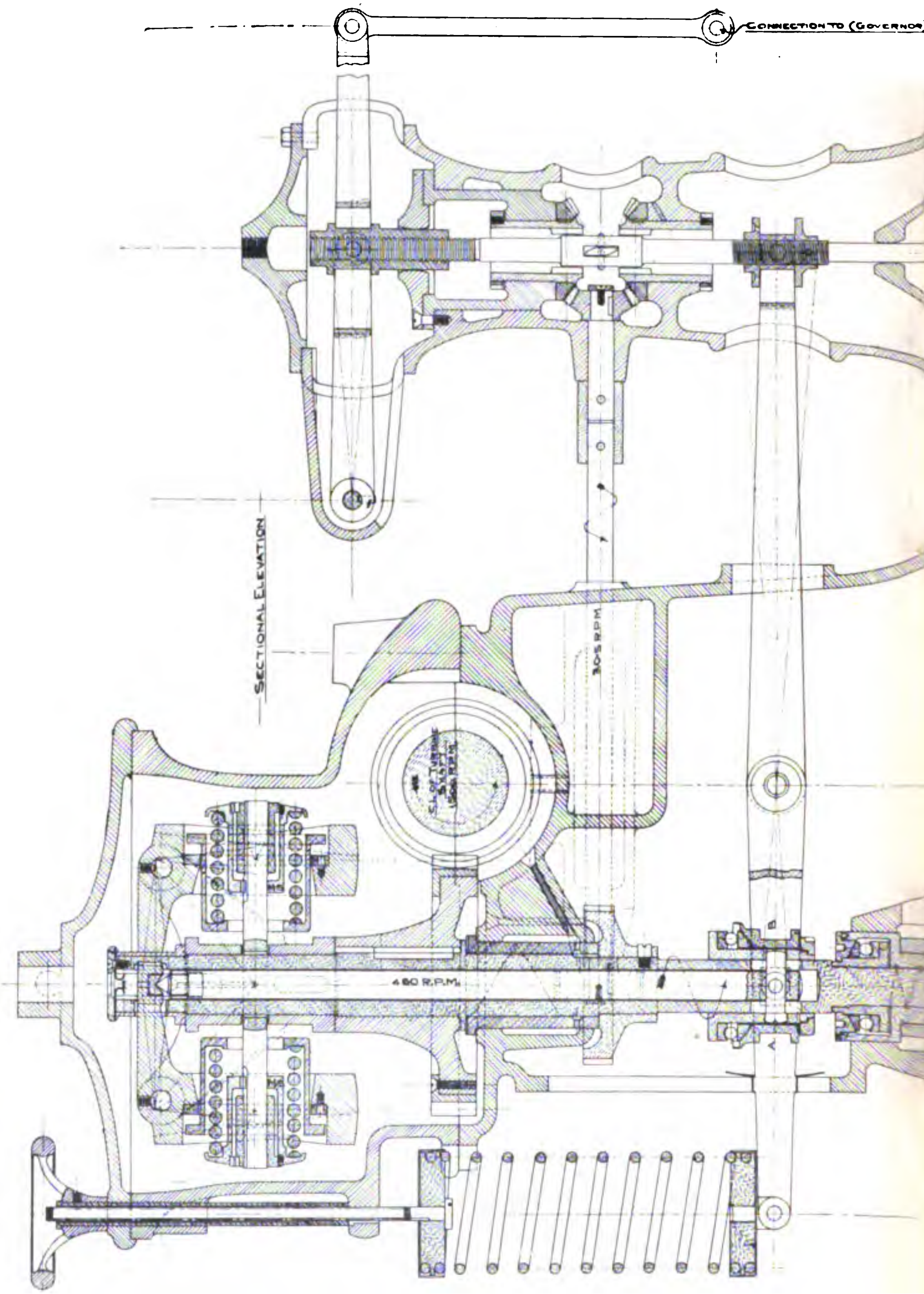
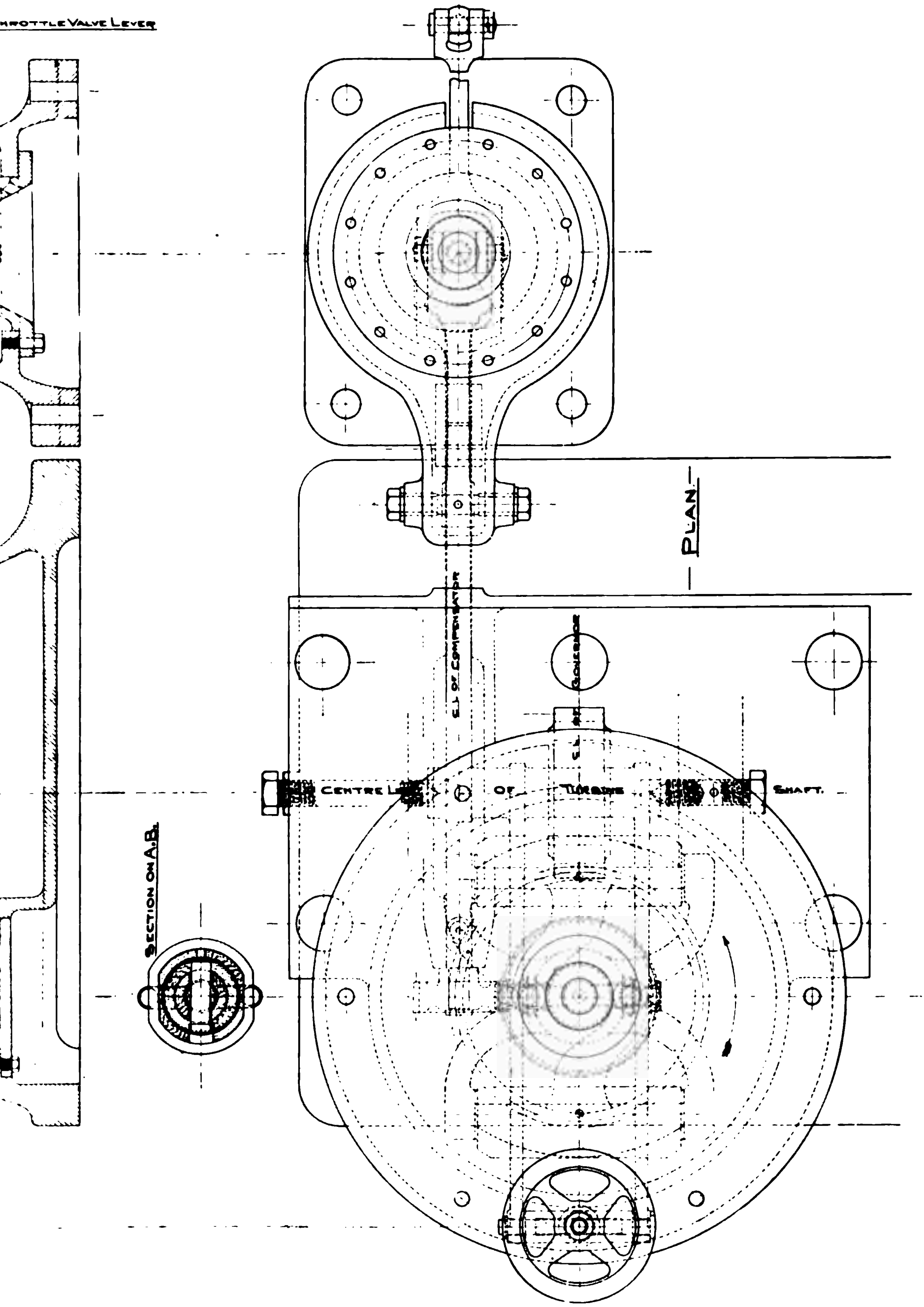


FIG. 156.—Throttling Govern...

[*To face page* 234.



Rateau. (*From Messrs Fraser & Chalmers.*)

Bearings.—In smallest units there are two bearings, cast in one piece with the casing; larger sizes have them screwed on the ends of the turbine casing, and still larger units have separate bearings and glands, or three bearings, as shown in Fig. 149, p. 227,[1] while the largest sizes have separate cylinders and an intermediate independent bearing (Fig. 157), the shafts being in some cases in two parts, with a coupling near the middle bearing.

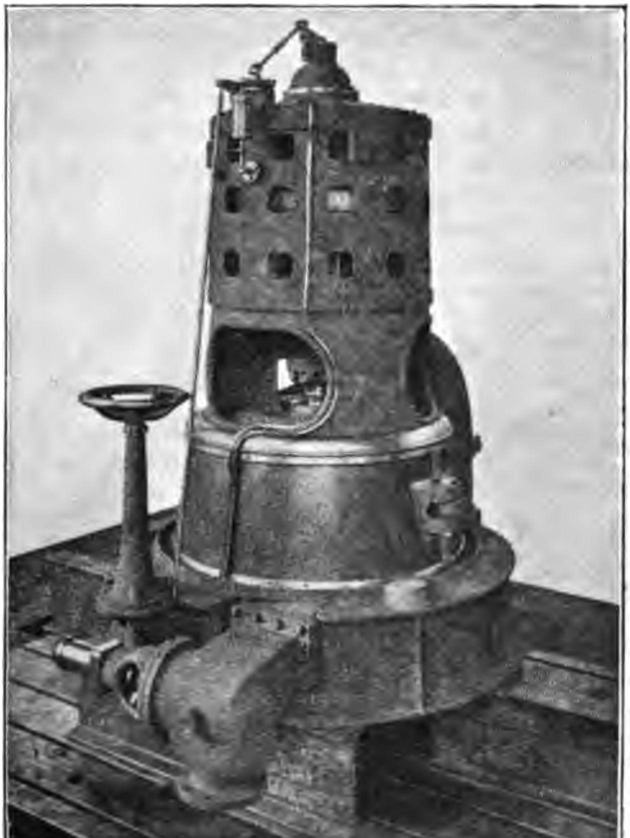


FIG. 158.—100 K.W. Vertical Turbine by Maschinenfabrik Oerlikon.

Professor Rateau states that they had trouble from oil getting into the steam in the design, now abandoned, which included a middle bearing inside the turbine casing.

[1] The internal bearing shown in Fig. 149 has been abandoned. In all recent machines all bearings are external to the turbine casing. Ring lubrication is used with white metal lined gun-metal bushes, and one ring is used for bearings up to 18 inches in length. A special scraper is fitted to deflect the oil from the ring into the spiral grooves provided for it.

Glands.—The stuffing box used by Messrs Sautter, Harlé & Compagnie, Paris, in their Rateau turbines, has a pressure of 12 lbs. per square inch absolute (·8 of atmospheric pressure) maintained in a chamber.

Two rings are held in place around the shaft by springs, and parallel with shaft by other springs, to prevent air leaking into that chamber.

Oerlikon-Rateau Turbines.—The vertical turbine illustrated admits steam through a 160-millimetre diameter inlet below the turbine, and the steam flows upwards, leaving the turbine through a 350-millimetre diameter exhaust pipe. The radius of the largest revolving wheel is 440 millimetres.[1]

Extent of Use.—In the summer of 1905 there were at work and under construction Rateau turbines, in sizes from 10 to 2300 horse-power, as follows:—

For ship propulsion	5,000	horse-power.
Electric Generators	31,450	„
Turbo-Pumps	2,784	„
Turbo-Fans and Air Compressors . .	800	„
	40,034	

TABLE LX.—DIMENSIONS, OUTPUTS, AND SPEEDS OF RATEAU TURBINES COUPLED TO OERLIKON GENERATORS.

Rated K.W.	Speed. Revolutions per Minute.	Length.	Breadth.	Height.	Weight per K.W.	
					Kgs.	Lbs.
100	3000	2000 [1]	1750	2900		
200	„					
300	„					
400	„					
500	„					
600	2000					
800	1500	... [2]	...	...	4	8·8
1250	„					
1500	„					
1600	„					
1750	„					
2000	„					
2500	„					
3000	1000					
3500	„					
4000	„					

[1] Figs. 158–160. [2] Figs. 162, 163.

[1] We are indebted to Professor Dr Stodola's third German edition of *The Steam Turbine* for these Figures, 158, 159, 160.

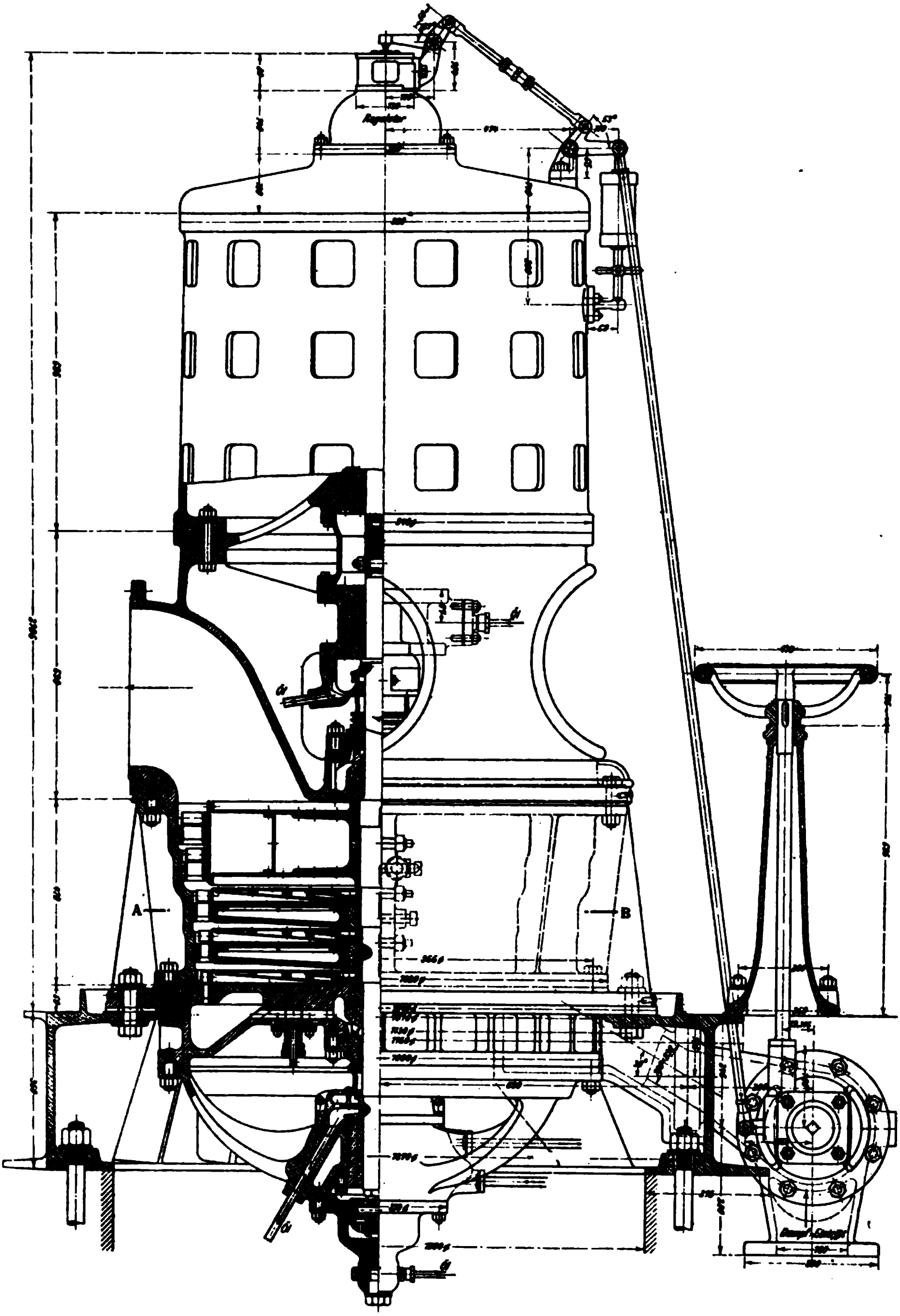


FIG. 159.—100 K.W. Rateau Steam Turbine by Maschinenfabrik Oerlikon, 3000 R.p.m. (Fig. 158).

Peripheral Speed.—Professor Rateau states the speed at which the steam and any particles which it may take with it strike the vanes, in his multicellular turbines, is a quarter, or even a fifth, of that usual in the de Laval turbine. The latter he stated as 1100 to 1200 metres per second (3600 to 3900 feet per second).[1]

Clearances.—The clearance between moving vanes or blades

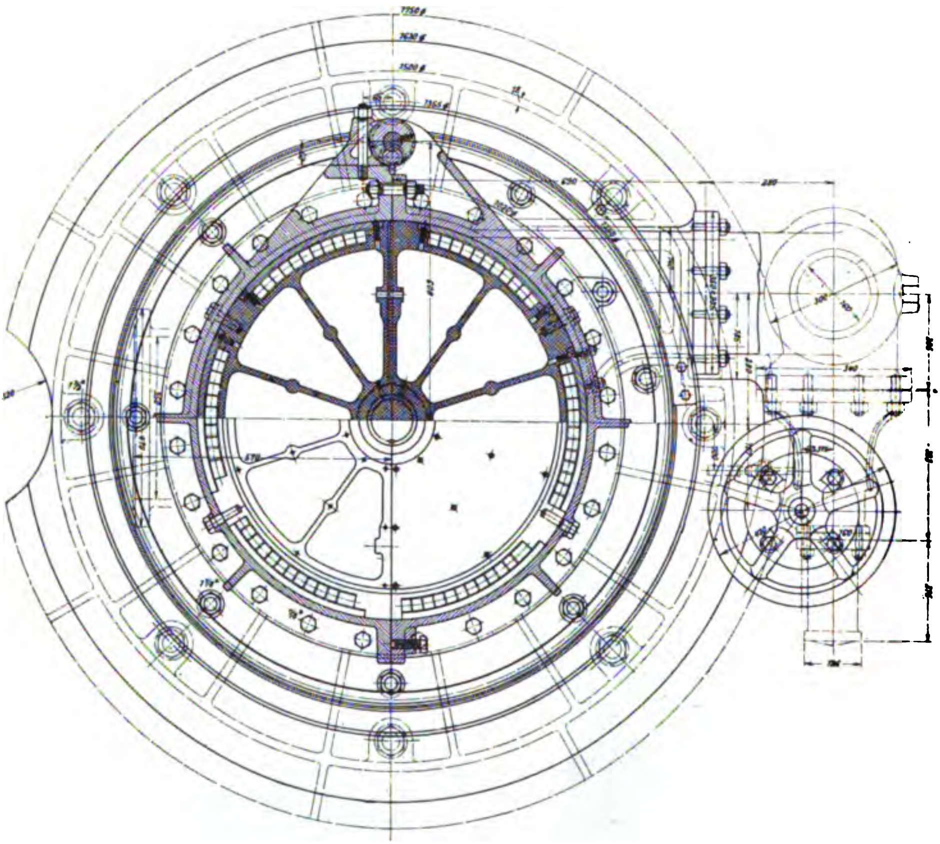


FIG. 160.—Plan of Fig. 159.

and fixed parts is 3 to 6 millimetres ($\frac{1}{8}$ to $\frac{1}{4}$ inch). The shaft is bushed, as stated above, in each diaphragm, which offers when new only a small annulus around the shaft for leakage—0·2 millimetre (·008 inch) being allowed here. The clearance on the exhaust side of the vanes or blades is $\frac{3}{8}$ to $\frac{5}{8}$ inch.

Other Applications.—Professor Rateau has designed centrifugal pumps and fans and compressors for coupling to his steam

[1] Consult page 32.

turbines, the combination in each case having high efficiency. One of the tests he quoted at the Conference of the Institution of Civil Engineers is as follows :—

TABLE LXI.—RATEAU STEAM TURBO-PUMP.[1]

Approximate horse-power . . .	200	
Total height of lift . . .	212 metres	695 ft.
Quantity lifted per hour . .	180 cu. m.	396,000 lbs.
" " minute .	3000 kgms.	6600 lbs.
Initial steam-pressure . .	6·65 kg. per sq. cm.	94·5 lbs. per sq. in.
Vacuum	63 cm. of mercury	24·8 inches of mercury.
Equivalent absolute back pressure	·17 kg. per sq. cm.	2·4 lbs. per sq. in.
Revolutions per minute . .	3200	
Useful work done per minute .	636,000 kgm.-metres	4,587,000 ft. lbs.
" " " .		139 Horse-power.
Theoretical quantity of steam necessary to do 1 useful horse-power, *i.e.* at 100 per cent. efficiency	4·75 kgm.	10·5 lbs.
Quantity actually used per useful horse-power . . .	13·6 kgm.	30 lbs.
Net efficiency of Turbo-Pump .	35 per cent.	35 per cent.

[1] Further similar tests showing 36 per cent. efficiency were put forward, in Professor Rateau's reply to a discussion, for comparison with figures of 31 per cent. to 35 per cent. given for Parsons' Steam Turbo-Pumps by Mr C. W. Darley,—Conference of the Institution of Civil Engineers, 1903.

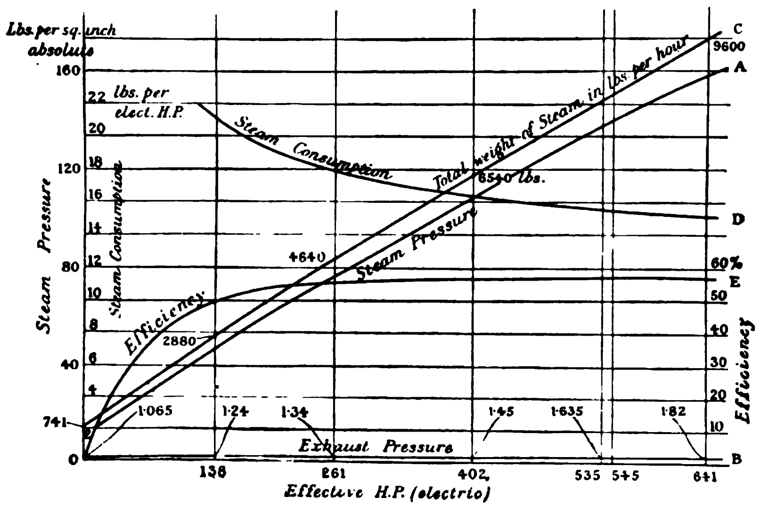


FIG. 161.—Sautter, Harlé & Co.'s 500 Horse-power (370 K.W.) Rateau Turbines at Peñarroya, Spain. English Units. For lbs. per K.W. Hour see Table LXIV. (From *Proc. Inst. Mech. Engrs.*)

High-lift centrifugal pumps are at work up to heads of 2000 feet, at efficiencies of 65 to 75 per cent.

Power consumed by Auxiliaries.—Professor Rateau gave the increase in work on air and circulating pumps to maintain

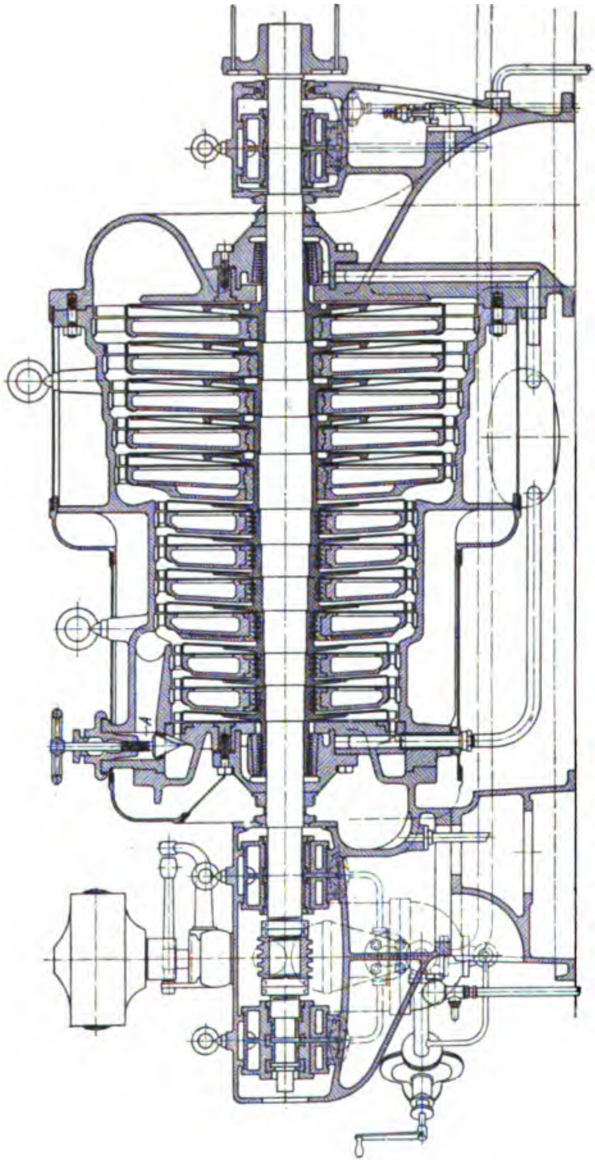


FIG. 162.—Rateau Steam Turbine by Maschinenfabrik Oerlikon, Schweiz, 1904, 700 K.W., 1500 R.p.m.

28-inch vacuum (0·068 kgm. per sq. cm. absolute) as compared with 26-inch vacuum (0·136 kgm. per sq. cm.) as not more than 2 per cent. to 3 per cent., while the saving in steam consumption

of the turbine is theoretically 12 per cent. with 10 atmospheres initial pressure.

Calculations on a 2000-kilowatt Rateau Turbine.—Assuming 200 lbs. per sq. inch, 29 ins. vacuum, 350° C. temperature

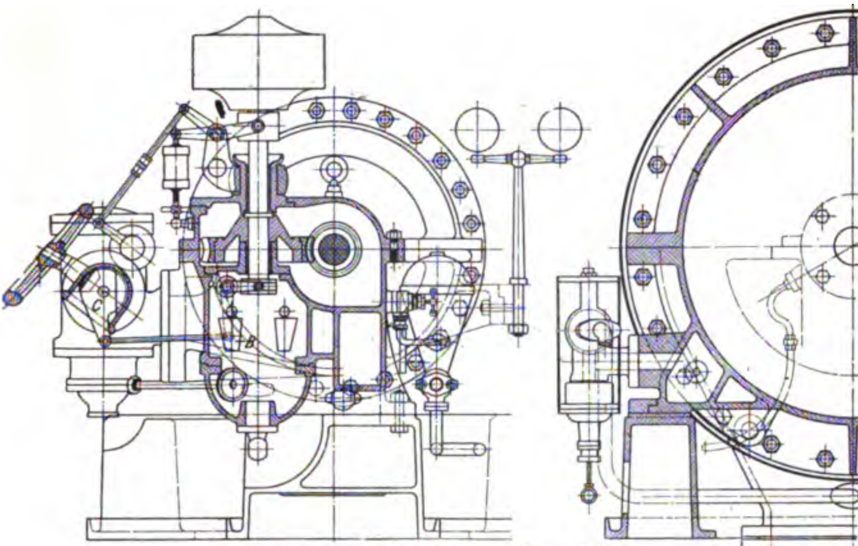


FIG. 163.—End Views of Fig. 162.

of steam, a steam consumption of 8·5 lbs. per horse-power-hour, *i.e.*, 11·9 lbs. per kilowatt-hour, using 96 per cent. efficiency, from Fig. 16, p. 38.

TABLE LXII.—EFFECT OF REDUCING THE VACUUM IN LOW-PRESSURE RATEAU TURBINE WITH HEAT ACCUMULATOR.[1]

Admission to Turbine.			Condenser.			Steam consumed.		
Absolute pressure.		Inches of Mercury.	Type.	Absolute Pressure. Kg. per sq. cm.	Vacuum Inches of Mercury.	Per K.W. Hr.		Percentage increase with reduced Vacuum.
Kg. per sq. cm.	Lbs per sq. in.					Kg.	Lbs.	
2	28·5	(14 lbs. gauge)	Surface	·08	27·7	12·6	27·8	100%
2	„		Jet	·13	26·3	14·5	32	115%
2	„	Vacuum	Ejector	·18	24·7	16·3	36	130%
1	14·2	1 in.	Surface	·08	27·7	16·3	36	100%
1	„		Jet	·13	26·3	19·6	43	120%
1	„		Ejector	·18	24·7	22·4	49·5	137%
0·5	7·1	15½ in.	Surface	·08	27·7	22·4	49·5	100%
0·5	„		Jet	·13	26·3	29·2	64·5	132%
0·5	„		Ejector	·18	24·7	38·0	84	170%

[1] From Mr Walter Rappaport on "The Rateau Steam Turbine," *The Electrical Review*, June 17, 1904, p. 1009. Mr P. J. Mitchell before West of Scotland Iron and Steel Institute, Dec. 1904, *Engineering*, Dec. 16, 1904, p. 831.

The normal case is the middle set in Table LXII. above, where the steam goes to the turbine at atmospheric pressure.

TABLE LXIII.—TEST OF 350 K.W. RATEAU MULTICELLULAR TURBO-ALTERNATOR FOR THE SOCIÉTÉ PAVIN DE LAFARGE AT TEIL (ARDÈCHE).

3000 *R.p.m.*, 3-*Phase*, 1000 *Volts—one of three sets.*

Test at Load.	Full Load 356 K.W.		Half Load 176 K.W.	
Steam per hour	3326 Kg.	7340 lbs.	1834 Kg.	4000 lbs.
„ „ K.W. hour	9·35 „	20·3 „	10·4 „	23 „
Temperature of steam	286° C.	547° F.	288° C.	550° F.
Superheat	96° C.	176° F.	92° C.	165° F.
Steam pressure *absolute*—				
Before the stop valve	11 kg. per sq. cm.	150 lbs. per sq. in.	14·4 kg. per sq. cm.	205 lbs. per sq. in.
After „ „ „	10·1 „ „	144 „ „	5·7 „ „	81 „ „
Exhaust	0·19 „ „	2·7 „ „	0·13 „ „	1·8 „ „
Vacuum in condenser	62·3 cm.	24·5 inches	66·8 cm.	26·25 inches.
Total efficiency	56 per cent.	56 per cent.	44·4 per cent.	44·4 per cent.

The following are results of tests on the first of three Rateau turbines driving continuous-current generators at the mines at Peñarroya, Spain :—

TABLE LXIV.—TEST OF 500 E.H.P. (370 K.W.) RATEAU TURBO-GENERATOR, FIRST FOR PENARROYA, BY SAUTTER, HARLÉ & CO. (Fig. 157.)

Fig. 161 gives these in curves using English units.

Test Load in per cent. of rated Load.	127%	108%	106%	80%	52%	27%	Fields excited no Load.
Load E.H.P.[1]	641	545	535	402	261	138	
K.W.	**470**	**400**	**393**	**295**	**192**	**101**	
Revolutions per minute	**2400**						
Steam pressure—							
Kg. per sq. cm. *absolute*	**11**	**9·8**	**9·7**	**7·6**	**5·4**	**3·3**	**0·75**
Lbs. per sq. inch gauge	140	125	123	93	63	32 lbs.	7½ in. vacuum
Vacuum (*mercury*)	26·2″	26·7″	26·9″	27″	27·2″	27·5″	27·6″
Kg. per sq. cm. *absolute*	**0·128**	**0·115**	**0·11**	**0·102**	**0·094**	**0·087**	**0·075**
Lbs. „ „ *inch* „	1·8	1·6	1·5	1·4	1·3	1·2	1·1
Superheat	**10° C.**	**10° C.**	zero	zero	zero	zero	zero
Steam consumed—							
Kg. per hour	**4345**	**3757**		**2960**	**2100**	**1300**	**336**
Lbs. „ „	9600	8300		6540	4640	2880	741
Kg. per E.H.P.	**6·74**	**6·87**	**7·03**	**7·4**	**8·12**	**9·52**	
„ „ K.W.H.	**9·15**	**9·33**	**9·55**	**10**	**11**	**12·9**	
Lbs. „ „	20·2	20·5	21·3	22	24·3	28·5	
Total efficiency	**58·1%**	**58·1%**	**56·8%**	**55·8%**	**54·8%**	**49·2**	

[1] of 736 watts.

Copper brushes are used here.

The no-load steam consumption with fields excited is 10 per cent. of the full-load steam consumption.

The second set (of three) for Peñarroya was submitted to a competent committee, Professor Stodola, Professor Wyssling, and Professor Farny, of the Zurich Polytechnicum, and their results are given in the following Tables taken from the English translation by Dr L. C. Loewenstein of Professor Dr. Stodola's 2nd German edition of *The Steam Turbine* (Constable, 1905).

TABLE LXV.—(IN METRIC UNITS.)

TESTS WITH THE RATEAU TURBINE BY SAUTTER, HARLÉ & CIE., PARIS.

	Test Number	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
Output from Dynamo K.W.		Light without excit'n.	Light with excit'n.	58·45	107·5	172·35	279·9	127·9	366·0	440·1	436·5	344·7	463 9	470·27
Speed R.p.m.		2 196	2 181	2 186	2 184	2 181	2 190	1 064	2 101	2 200	2 200	1 996	2 360	2 310
Duration of Test minutes		30	18	25	40	50	85	20	130	30	26	10	22	30
At entrance to admission valve:														
Kgs. per sq. cm. abs.		12·33	12·66	12·26	12·38	12·31	11·99	10·91	11·84	12·73	11·36	11·45	15·73	15·20
Temp. °C.		188·2	189 6	190·9	191·2	193·2	195·1	188·6	197·5	197 7	195·9	(195·9)	212·6	209·6
,, of Saturation °C.		188·2	189·3	190·2	188·3	188·2	186·9	182·6	186·4	189 6	184·5	184·8	199·5	197·8
Superheat °C.		0·0	0·3	0·7	2·9	5·0	8·2	6·0	11·1	8·1	11·4	(11·4)	13·1	11·8
At entrance to first guide:														
Kgs. per sq. cm. abs.		0·66	0·875	2·28	3·14	4·49	6·71	4·54	8·43	10·1	8·68	8·65	10·71	10·32
Temp. °C.		118·3	124·6	141·5	152·4	164·9	174	165·3	182·1	185·9	185·1	182·1	193·9	192·1
,, of Saturation °C.		83·7	95·4	123·7	134·3	147·0	162·4	147·4	171·6	179·3	172·3	172·3	181·8	180·3
Superheat °C.		34·6	29·2	17·8	18·1	17·9	11·6	17·9	10·5	6·6	12·8	9 8	12·1	11·8
At intermediate pipe: Kg. per sq. cm. abs.		0·120	0·140	0·266	0·383	0·545	0·802	0·546	0·999	1·20	1·26	0·99	1·24	1·27
At exhaust pipe: Kg. per sq. cm. abs.		0·106	0·103	0·088	0·091	0·0935	0·106	0·091	0·115	0·131	0·141	0·128	0·151	0·13
Circulating water suction °C.		12·9	11·5	12·2	17·5	16·5	18·2	16·72	15·8	16·04	..	..	21 5	13·9
,, discharge °C.		14·3	13·2	16 6	22·9	24·0	28·0	24·4	26·8	27·7	..	..	33 8	27·2
Condensed steam °C.		..	23·0	20·0	21·4	22·5	27·0	23·7	29·8	32·5	33	37	40	33
Total steam consumption per hour	Kg.	338·0	445·0	1003·2	1483·5	2044·8	2976·0	2085·0	3754·0	4385·0	4592·3	3768·0	4640·5	4647·0
Steam consumption per K.W. hour exclusive of work of air pump	Kg.	..	..	17·16	13·80	11·86	10·63	16·30	10·25	9·96	10 52	10·93	10·02	9·88
Efficiency of Dynamo	per cent.	..	..	74·0	84·0	90·2	92·0	86·0	92·4	93·0	92·9	92·3	93·3	93·4
Effective power of Turbine	H.p.	..	..	107·3	174·0	260·2	421·5	202·0	538·2	643·0	637·7	507·4	674·1	684·0
Steam consumption per effective H.p. hour (exclusive of work of air pump)	Kg.	..	..	9·35	8·52	7·86	7·04	10·32	6·97	6·82	7·20	7·42	6·88	6·79
Thermodynamic efficiency referred to the useful electrical work at the brushes of the dynamo and to the steam condition at entrance to the 1st guide wheel	per. cent.	..	..	43·3	49·5	52·4	54·4	37·7	54·3	54·9	51·6	51·6	55·2	54·9

TABLE LXV.—(IN ENGLISH UNITS.)

TESTS WITH THE RATEAU TURBINE BY SAUTTER, HARLÉ & CIE., PARIS.

	Test Number	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
Output from Dynamo K.W.		Light without excit'n.	Light with excit'n.	58	107	172	280	128	366	440	436	345	463	470
Speed R.p.m.		2196	2181	2186	2184	2181	2190	1054	2101	2200	2200	1998	2360	2310
Duration of Test minutes		30	18	25	40	50	35	20	180	30	26	10	22	30
At entrance to admission valve:	lbs. per sq. in. abs.	175·4	180·1	174·4	176·1	175·1	170·5	155·2	168·4	181·1	161·6	162·9	223·7	216·2
Temp.	°F.	370·8	373·3	375·6	376·2	379·8	383·2	371·5	387·5	387·9	384·6	384·6	414·7	409·3
„ of Saturation	°F.	370·8	372·7	374·4	370·9	370·8	368·4	360·7	367·5	373·3	364·1	364·6	391·1	388·0
Superheat	°F.	0·0	0·5	1·3	5·2	9·0	14·8	10·8	20·0	14·6	20·5	20·5	23·6	21·2
At entrance to first guide:	lbs. per sq. in. abs.	9·387	12·45	32·13	44·66	63·86	95·44	64·57	119·9	143·7	123·5	123·0	152·3	146·8
Temp.	°F.	244·9	256·3	286·7	306·3	328·8	345·2	329·5	359·8	366·6	365·2	359·8	381·0	377·5
„ of Saturation	°F.	182·7	203·7	254·7	273·7	296·6	324·3	297·3	340·9	354·7	342·1	342·1	359·2	356·5
Superheat	°F.	62·3	52·6	32·0	32·6	32·2	20·9	32·2	18·9	11·9	23·0	17·6	21·8	21·2
A intermediate pipe:	lbs. per sq. in. abs.	1·707	1·991	3·783	5·448	7·752	11·41	7·766	14·21	17·07	17·92	14·08	17·64	18·06
At exhaust pipe:	„	1·508	1·465	1·252	1·294	13·30	1·508	1·294	1·636	1·863	2·006	18·21	2·148	1·849
Circulating water suction	°F.	55·2	52·7	54·0	63·5	61·7	64·8	62·10	60·4	60·9	..	..	70·7	57·0
discharge	°F.	57·7	55·8	61·9	73·2	75·2	82·4	75·9	80·2	81·9	..	..	92·8	81·0
Condensed steam	°F.	..	73·4	68·0	70·5	72·5	80·6	74·7	85·6	90·5	91·4	98·6	104·0	91·4
Total steam consumption per hour	lb.	745	981	2211	3270	4508	65 1	4596	827	9667	10123	8307	10280	10245
Steam consumption per K.W. hour exclusive of work of air pump	lb.	..	..	37·83	30·42	26·15	23·43	35·93	22·60	21·96	23·19	24·10	22·09	21·78
Efficiency of Dynamo	per cent.	..	..	74·0	84·0	90·2	92·0	86·0	92·4	93·0	92·9	92·3	93·3	93·4
Effective power of Turbine	H.p.	..	..	105·8	171·6	256·6	416·7	199·2	530·8	634·2	629·0	500·5	664·9	674·7
Steam consumption per effective H.p. hour (exclusive of work of air pump)	lb.	..	..	20·90	19·04	17·57	15·74	23·07	15·57	15·24	16·09	16·585	15·38	15·18
Thermodynamic efficiency referred to the useful work at the brushes of the dynamo and to the steam condition at entrance to the 1st guide wheel	per cent.	..	..	43·3	49·5	52·4	54·4	37·7	54·3	54·9	54·6	51·6	55·2	54·9

TABLE LXVI.—TEST[1] ON A 500 K.W. RATEAU-SAUTTER, HARLÉ & CO. TURBINE.

K.W.	Speed.	Absolute Steam Pressure.				Condenser.		Steam consumed per K.W. Hour.	
		At Boiler.		In Front of Turbine.					
	R.p.m.	Kg. per sq. cm.	Lbs. per sq. in.	Kg. per sq. cm.	Lbs. per sq. in.	Absolute Kg. per sq. cm.	Vacuum Inches of Mercury.	Kg.	Lbs.
							in.		
376	2050	12	170	9·6	136	0·115	26·5	9·75	21·5
387	2213	,,	,,	,,	,,	,,	,,	9·52	21·0
394	2420	,,	,,	,,	,,	,,	,,	9·45	20·8
382	2025	16	228	,,	,,	,,	,,	9·58	21·1
394	2259	,,	,,	,,	,,	,,	,,	9·28	20·4
400	2429	,,	,,	,,	,,	,,	,,	9·13	20·1
445	2011	,,	,,	11·0	156	0·128	26·3	9·58	21·1
460	2225	,,	,,	,,	,,	,,	,,	9·26	20·4
473	2429	,,	,,	,,	,,	,,	,,	9·00	19·8

[1] From *The Electrical Review*, June 17, 1904, p. 1011.

TABLE LXVII.—TEST ON A 1000 K.W. RATEAU TURBINE MADE AT MASCHINENFABRIK, OERLIKON, SWITZERLAND.

K.W.	Speed r.p.m.	Absolute Steam Pressure.				Condenser.		Temperature Centigrade.	Steam consumed per K.W. Hour.	
		At Boiler.		In front of first moving wheel.						
		Kg. per sq. cm.	Lbs. per sq. in.	Kg. per sq. cm.	Lbs. per sq. in.	Absolute Kg. per sq. cm.	Vacuum in. of Mercury.		Kg.	Lbs.
194	1500	13·1	186	2·17	30·8	·078	27·7	148	14·5	32
425	,,	10·9	155	4·06	57·6	·083	27·6	155	11·3	25
659	,,	11·3	160	5·99	85·	·14	25·7	162	10·8	23·8
871	,,	12·7	180	7·89	112·	·222	23·5	175	11·2	24·7
1024	,,	12·6	179	8·19	116·	·171	25	176	9·97	22

TABLE LXVIII.—TESTS,[1] APRIL 5, 1902, ON 225 K.W. LOW-PRESSURE RATEAU TURBINE WITH HEAT ACCUMULATOR FOR PIT NO. 5, BRUAY MINES, PAS-DE-CALAIS. (Fig. 166.)

K.W.	Speed r.p.m.	Admission to Turbine.					Condenser.		Steam Consumed per K.W. Hour.		Thermodynamic Efficiency.[3]
		Temperature.		Absolute Pressure.		Vacuum in. of Mercury.[2]	Absolute Pressure. Kg. per sq. cm.	Vacuum in. of Mercury.[2]	Kg.	Lbs.	
		C.°	F.°	Kg. per sq. cm.	Lbs. per sq. in.						
No Load. Not excited.	1610	111	232	0·14	1·9	25·6	·09	27·2	(570 per hour)	(1260)	
70	1589	111	232	0·38	5·4	18·5	·09	27·2	31·6	69·7	·49
141	1600	135	275	0·66	9·4	10·2	·13	26	26·0	57·3	·53
203	1591	137	278	0·90	12·8	2·9	·16	25	24·5	54·0	·58
232	1598	147	297	1·03	14·7	zero	0	24	24·2	53·5	·55

Carbon brushes are used here.

[1] From "*Different Applications of Steam Turbines,*" by Professor Rateau, Chicago, 1904. The tests were made at works of Messrs Sautter, Harlé et Cie., Paris, by M. Sauvage, Chief Engineer of the French Corps of Mines, and M. Picou, Electrical Engineer for the Engineers of the Bruay Coal Mines, Pas-de-Calais, in 1902.

[2] It will be easiest for those accustomed to the vacuum gauge to note the range between columns 7 and 9.

[3] The efficiency is the ratio of dynamo output to the theoretic energy in the steam supplied.

TABLE LXIX.—TEST OF 400 E.H.P. RATEAU TURBINE AT GENERATING STATION OF CIE. ÉLECTRIQUE DE LA LOIRE.

Pressure	170 lbs. per sq. in. *absolute.*		
Exhaust	2·85 ,, ,, ,,		
Output	388 E.H.P. at generator terminals.		
,, (at 736)	285 K.W.	,,	,,
Steam per E.H.P. hour .	19·2 lbs.	,,	,,
,, K.W. hour . .	26 ,,	,,	,,
Combined efficiency . .	4·87 per cent.		

This turbine has only twelve revolving wheels.

Deductions from Tests.—Sufficient tests on independent machines are not available for comparisons, such as have been made in the earlier chapters of this book, to be attempted here.

Regenerative Heat Accumulators.—These, being adjuncts to steam turbines, deserve consideration here. They have been made in four forms.[1]

[1] *Bulletin de la Société de l'Industrie Minérale.* "The Utilisation of Exhaust Steam by the application of Steam Accumulators and Condensing Turbines," North of England Institute of Mining and Mechanical Engineers. *Electrical Review*, p. 312, Aug. 21, 1903. *Engineering*, July 3, 17, 1903.

The idea of storing heat is not a new one. Mr Druit Halpin patented a system for use with steam boilers.

His system is most useful, as it provides a valuable means of equalising the work on the boilers of central generating stations having heavy peak loads, and consists briefly in passing the surplus steam generated at periods of light load to a reservoir, where it is injected into water and serves to raise the water to a temperature near the boiling point at the boiler pressure.

A large quantity of water is thus ready to be flashed almost instantly into steam when a sudden load comes on, by the addition then of a relatively small amount of heat.

The idea of using exhaust steam from a reciprocating engine in a turbine is also not a new one, and first originated with the Hon. C. A. Parsons, who took out a patent covering the application of a turbine to a reciprocating engine, to more fully utilise the expansion of the steam.

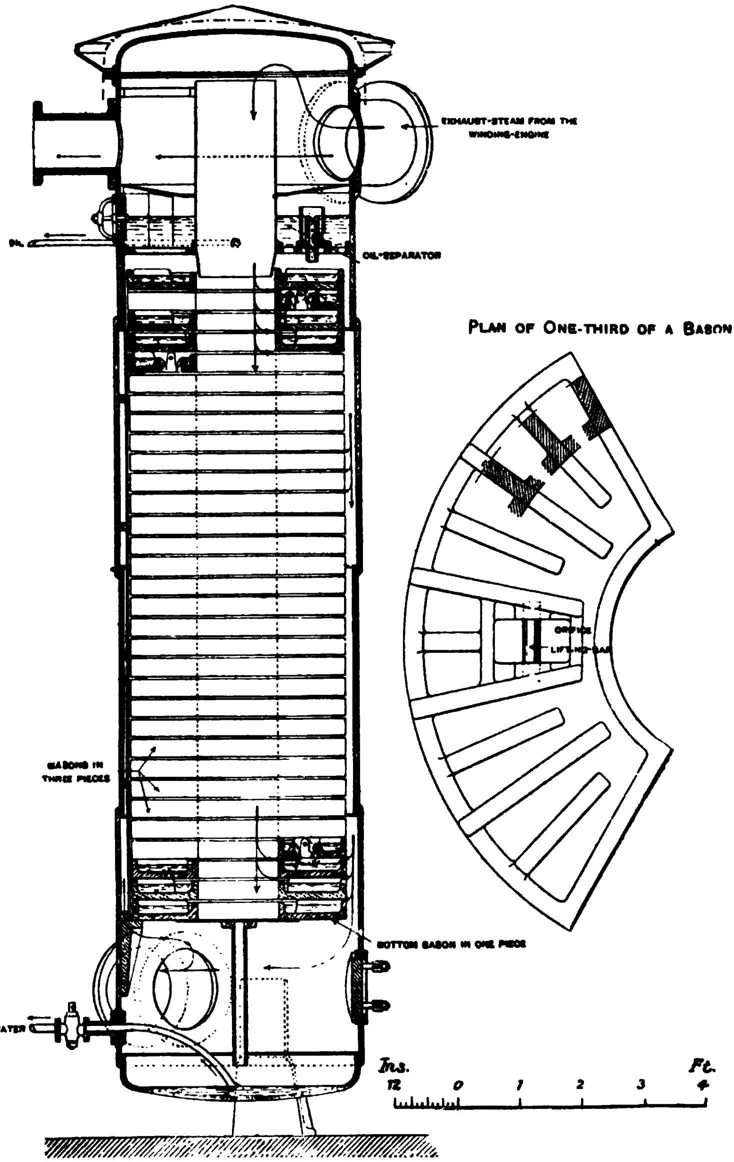
The combination of Professor Rateau, however, was produced to solve another problem, *i.e.*, the combination of a turbine with an intermittent working engine, such as a rolling mill engine or a colliery winding engine of the reversing type, which has regular stops of from 5 seconds to 5 minutes duration.

The practical solution of this problem necessitated the bridging over of these frequent stops, to render the various portions of the plant mutually independent, and to devise an apparatus capable of the most rapid absorption and emission of heat.

The steam leaving the primary engine enters an accumulator regenerator, which may be either of the cast-iron tray, the old rail, or the water type.

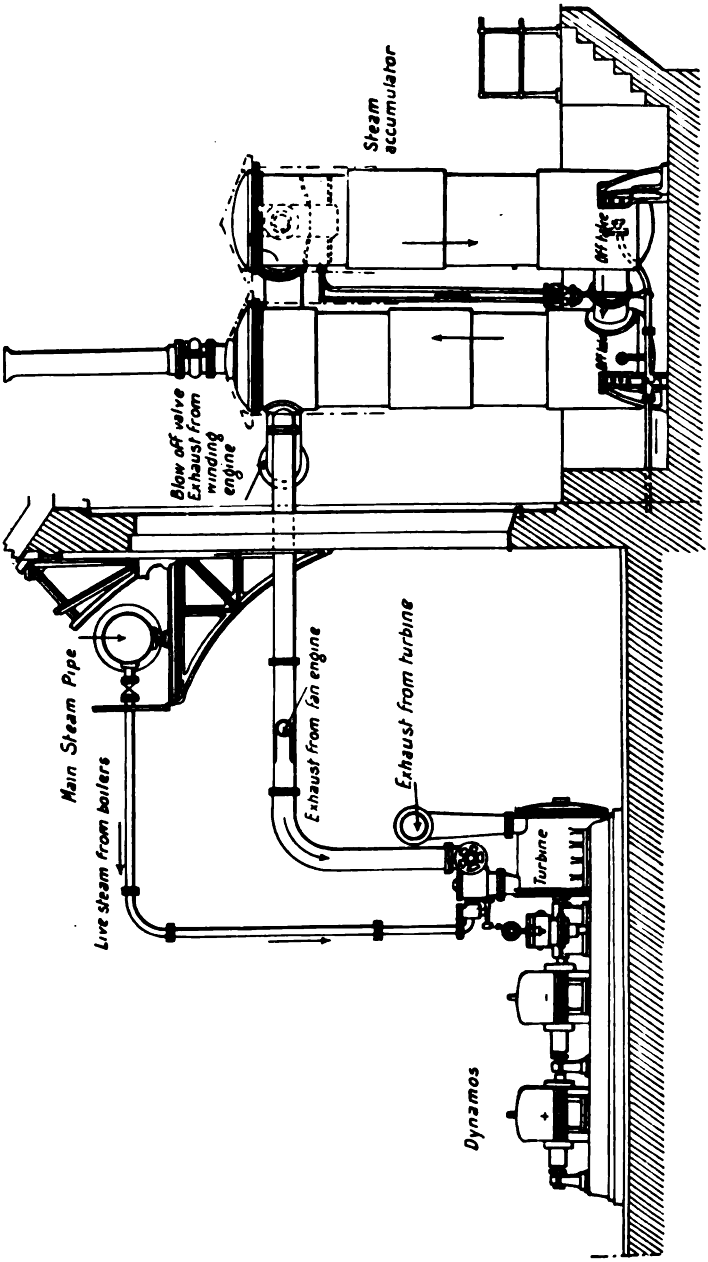
Figs. 164 and 165 show one of these, as installed in August 1902 at Pit No. 5, Bruay Coal Mines, Pas-de-Calais. There are in this case, in each of three such accumulators, shown in Fig. 166, 32 annular cast-iron dishes, each made up of three parts, such as is shown in Fig. 165, except the bottom one, which is in one piece, with about 2 inches depth of water in each. This gives 30 tons of iron and over 3 tons of water, into which the steam from the reciprocating winding engine passes, and when in excess of the requirements of the turbine the temperature and pressure in the accumulator rise, the working range being between about 212° F. and zero gauge pressure, and about 230° F. and 6 lbs. per square inch. A large relief valve is installed and set for any desired pressure to avoid undue back pressure on the primary engine.

The steam enters at the bottom and passes up the sides until



FIGS. 164, 165.—Professor Rateau's Regenerative Steam Accumulator. (From *Proc. Inst. Mech. Engrs.*)

it reaches the baffle plate, placed half way up. This forces it to pass to the central passage, passing over the water contained in the



STEAM REGENERATION-PLANT AT THE BRUAY COLLIERY, PAS-DE-CALAIS.

FIG. 166.—Rateau Installation at Bruay.—Elevation.

(15¾ in. diameter) 400 mm. pipe, exhaust from main winding engine.
A1, A2, A3, three Rateau regenerative steam accumulators (only 2 visible).
(9⅞ in. diameter) 250 mm. pipe, main engine exhaust from A3 to turbine, T.
(7 in. diameter) 180 mm. pipe, exhaust from fan engine goes direct to turbine (not through accumulator).
T, Rateau Turbine direct-coupled to two continuous current generators (3 wire system).
(3 in. diam.) 75 mm. pipe, steam direct from boilers to Turbine in case supply from accumulators, A, is insufficient.
Governor with Denis Compensator regulates speed within 2 per cent. when load on generators and steam supply vary.
Automatic atmospheric exhaust on top of one accumulator.
Oil separator between the two accumulators in Fig. 166.
Low-pressure Turbine 1600 R.p.m. drives 2 generators, 250 volts, 400/450 amperes continuous current—225 K.W.

trays. This passage is blocked at the top by another baffle plate, causing it to pass from the central passage, over the surface of

the water, to the annular passage outside the trays. It then rises to the top of the vessel and passes to the turbine.

The action of the accumulator is as follows:—

The steam, in traversing it, gives up a portion of its heat to the cast-iron and to the water in condensing on the cooler surfaces.

When the primary engines stop, the turbine continues to draw steam from the accumulator and the pressure gradually drops. The moment this occurs, the heat given up to the cast-iron and water is gradually given off in the form of low-pressure steam.

Reunion Mines 600 H.-P. Accumulator Plant.—At the Reunion Mines of the Saragossa-Alicante Railway, Madrid, old rails are arranged to take the place of the pans of water described above, because, in this instance, the rails were "scrap" and cheap. Here the tanks are horizontal.

Fig. 173, page 258, shows an internal view of another accumulator of the old rail type, working at the Hucknall Torkard Collieries, Ld., No. 2 pit, near Nottingham, consisting also of a carefully stacked mass of old rails, so placed that the steam has to pass longitudinally through small passages. In doing so, part of its heat is given up to the metal, and water forms on the surfaces. Heat transference takes place as in the case of the cast-iron water type, and steam is regenerated as the pressure falls.

Bethune Mines Heat Accumulator.—At the Bethune Mines, Pas-de-Calais, a 350 horse-power accumulator of another form is in use. Several large pipes, with vertical passages between them, are arranged horizontally inside a horizontal cylinder which is nearly filled with water. The exhaust steam enters the pipes and passes into the passages through numerous small openings in the pipes, causing rapid movement of the water, which flows up and down through the passages and around the walls of the tank. Plates are arranged to direct the flow. Fig. 167 shows the design.

The steam entering these oval tubes forces out the water, and when it reaches the first row of holes, escapes through them and rises in the form of bubbles of steam. If the area of the first row is insufficient, the water-level in the oval tubes is further depressed, and the second row is uncovered until sufficient area is provided. Part of the steam, in passing through the water, is condensed, the remainder going to the turbine. When the primary engine stops, the pressure drops. The same regenerative action takes place;

the steam in the tubes expanding keeps the water circulating, and facilitates the regeneration just as the circulation in the first instance facilitated the condensation.

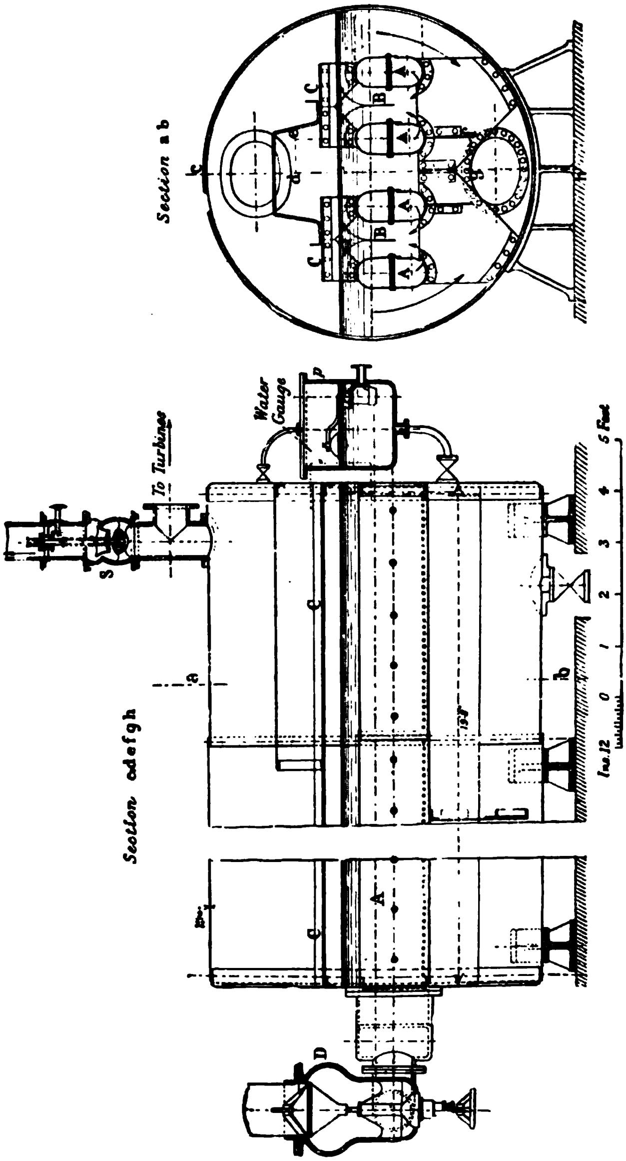


FIG. 167.—Rateau's Water Heat Accumulator. (From *Proc. Inst. Mech. Engrs.*, 1904, Chicago.) Type used at Bethune Mines. See also Figs. 168 and 169.

The tank appears to be 20 ft. long, 6 ft. 6 ins. diameter, containing 10 tons of water, and deals with 10,000 lbs. of steam per

hour, developing 350 horse-power[1] when the primary engine has stops of as much as, but not over, a minute.

The air compressor driven by this low-pressure turbine of 350 horse-power at 4500 revolutions per minute gives an air-pressure of 85 lbs. per square inch (gauge).

Another similar plant is described and illustrated in Figs. 168 to 171, page 253.

The heat accumulator has a double-beat relief valve to give a large area for a small lift in case the load on the turbine is too small to utilise the supply of steam.

Also, provision is made for taking boiler steam direct to the turbine through a reducing valve in case the primary engine is not working, or automatically when the absolute pressure in the accumulator falls below a predetermined amount. When the primary engine is not working, the valve between the accumulator and turbine is closed. Under these conditions the steam consumption rate is increased from 25 per cent. to 50 per cent. Naturally, the conditions of service in each case require careful study before it can be decided whether heat accumulation will prove economical.

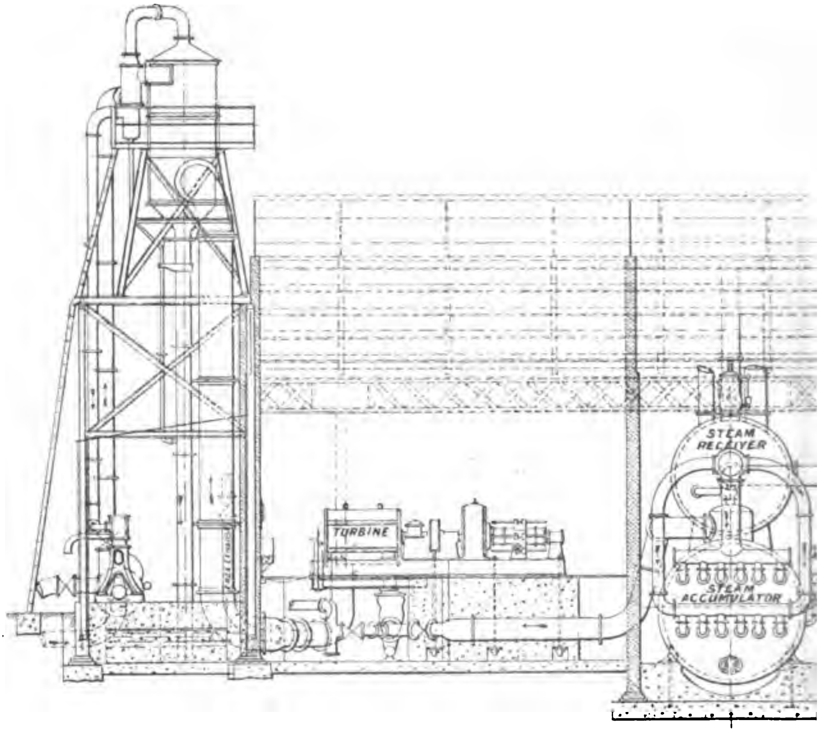
Supplementary High-Pressure Turbine.—When the primary engine is idle for long periods during which the turbine is needed, Professor Rateau provides an additional high-pressure section to the turbine, which avoids the loss of efficiency just mentioned. This section is not in use when the primary engine is running.

At Bruay.—The main winding engine winds on an average fifty times per hour from a depth of 750 ft., totalling about 200 tons, *i.e.* 2500 foot-tons per minute = 170 useful horse-power, and uses presumably 17,500 lbs. of steam. Of this, 3500 lbs. is assumed to be lost by condensation, leaving 14,000 lbs. per hour exhausted into the atmosphere. This, Professor Rateau calculated, would give at least 400 net electrical H.P.H. (about 300 kilowatt-hours) when utilised in his low-pressure condensing turbines at 35 lbs. per electrical H.P.H. (47 lbs. per kilowatt-hour).[2]

Professor Rateau also estimated the steam consumption of an unnamed rolling mill engine at 44,000 lbs. per hour in intermittent

[1] "The Utilisation of Exhaust Steam in Steam Turbines." Mr Battu before the Western Society of Engineers, 1904. *The Engineer*, Nov. 4, 1904, p. 455.

[2] The Bruay Mines turbine, tested by Messrs Sauvage and Picou (see Table LXVIII., page 246), was a 225 kilowatt turbine, and had 7 wheels, each 880 mm. (34⅝ inches) diameter, *i.e.* 7 expansions. *Engineering*, June 5, 1903, p. 746.



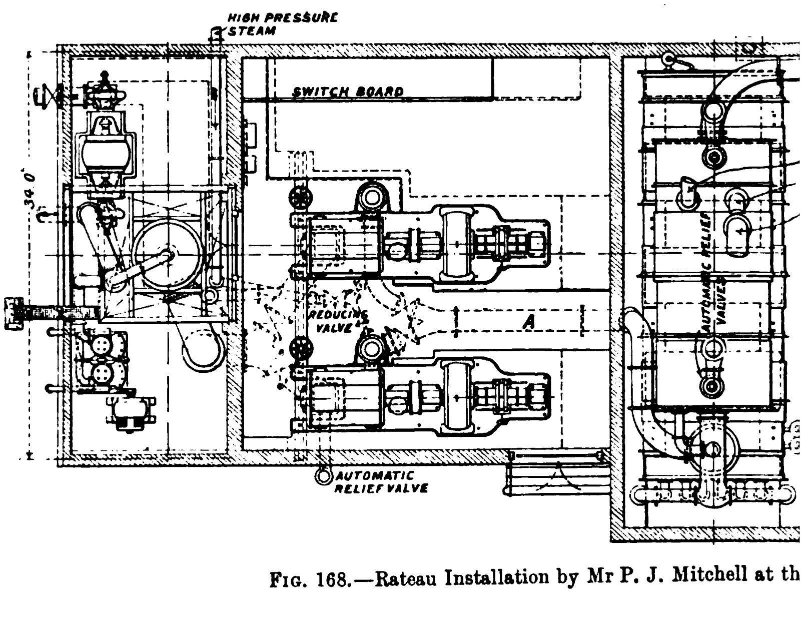
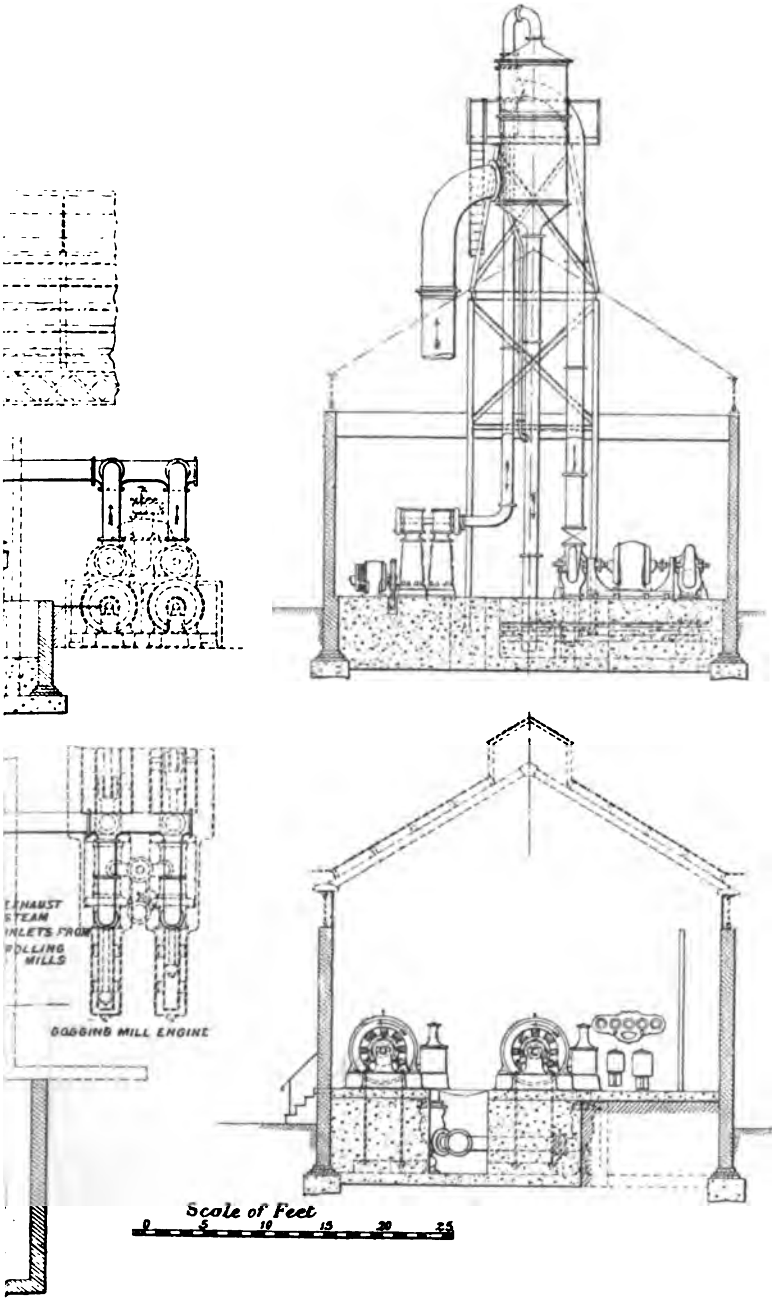


Fig. 168.—Rateau Installation by Mr P. J. Mitchell at th



: Hallside Works, Newton, of the Steel Co. of Scotland.

draughts, and he calculated that this would suffice, with heat accumulator and low-pressure turbine, to supply 1000 horse-power, or with the exhaust from steam hammers and all other engines to three times this amount. Of course, this is without increasing either boiler plant or coal consumption.

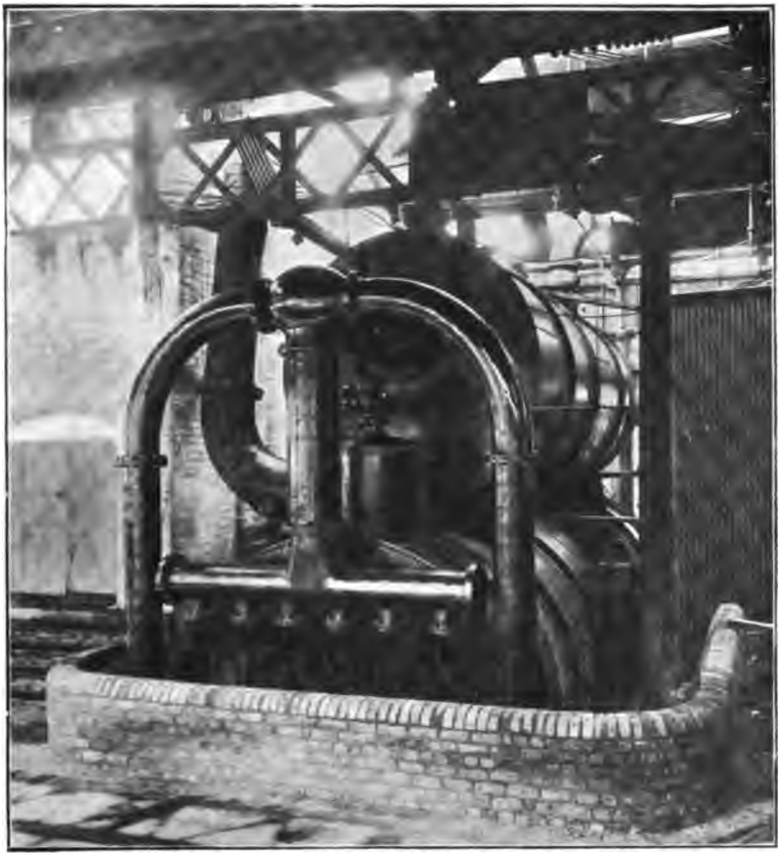


FIG. 169.—Rateau Heat Accumulator. Steel Co. of Scotland Nov. 1905.

HALLSIDE WORKS, NEWTON, LANARKSHIRE.

Fig. 168 shows the general arrangement of the plant at the works of the Steel Company of Scotland.

The primary engines exhausting to the accumulator are as follows:—

One cogging engine, 2 cylinders, each 40 inches diameter × 5 foot stroke.

One finishing main engine, 42 inches diameter × by 5 foot stroke.

Two small mill engines, driving 14 inch and 18 inch mills.

One 10 ton and one 4 ton steam-hammers.

The total amount of steam from these engines was estimated by Mr P. J. Mitchell, who designed the plant, and to whom we are indebted for all this data, as 41,000 lbs. per hour, after making deductions for pipe condensation, etc.

It was therefore decided to install two 450 kilowatt low-pressure turbo-generators, conforming to the then existing works pressure of 230 volts. The output of the mills having been largely increased in the last few months, makes it probable that another unit can be added, making the total power recovered from these engines 2100 E.H.P.

The accumulator shown in plan and elevation to the right is surmounted by a receiver which breaks the violent shocks of the exhaust steam. It communicates by means of pipes with the accumulator. The steam, on leaving the accumulator, passes through a 21 inch main to the inlet valves of the turbines. A high-pressure main is brought into the engine-room at the opposite end up to this pipe, and is fitted with the special reducing valve for supplying reduced pressure live steam to the turbines when the main engines are standing for roll changing, etc.

As the high-speed generating set supplying current to the works has been thrown out of operation by the installation of the turbines, no current is available for starting up the condensing plant, and the reducing valves being shut positively when pressure rises above 14·7 lbs. absolute, the turbines cannot be started without some special method of opening the reducing valve and running the turbine to atmosphere. This is provided, and a system of levers leading from the stop-valve enables the turbine to run to atmosphere until sufficient current is generated to start up the condensing plant, when the lever is released, and the plant works at or below atmospheric pressure.

The turbine exhausts to a barometric jet condenser capable of maintaining a 90 per cent. vacuum.

Figs. 170 and 171 show the turbine coupled to a Siemens direct-current generator, 1950 amperes, 230 volts, with special commutator, ventilating device, and carbon brushes.

The turbine has an output of 700 B.H.P. at 1500 revolutions per minute when exhausting to 27 inch vacuum with atmospheric inlet pressure. The efficiency compared with the theoretical duty

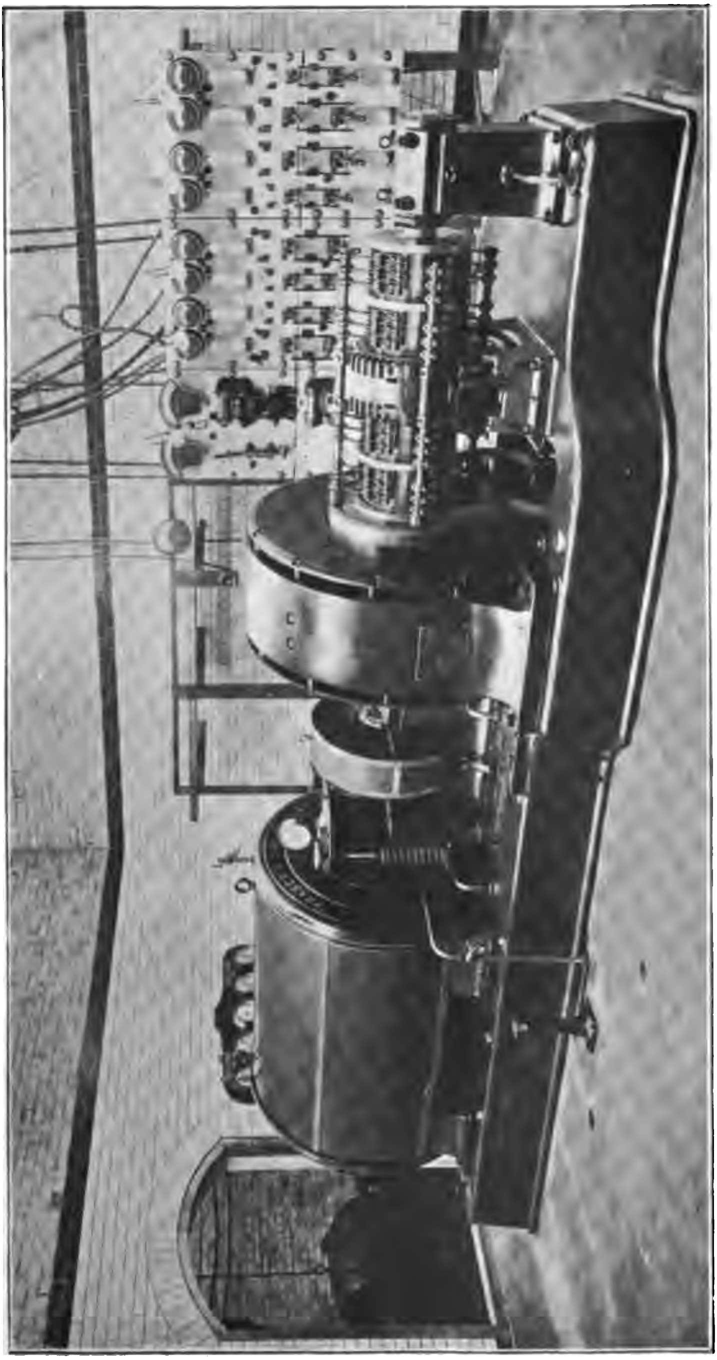


FIG. 170.—Rateau Low-Pressure Turbo-Generator by Messrs Fraser & Chalmers, at Steel Co. of Scotland, Nov. 1905. (See also Fig. 150, p. 227.)

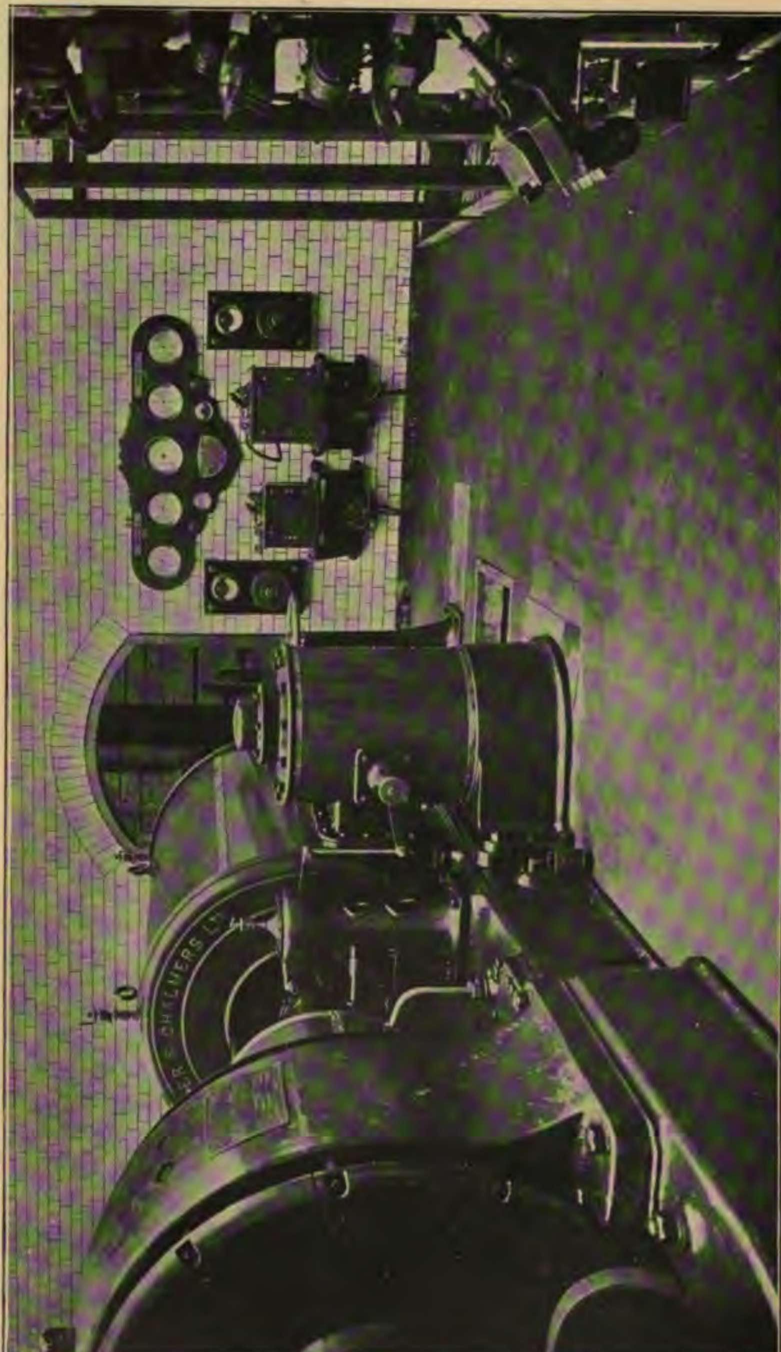


FIG. 171.—Opposite View to Fig. 170, showing Case of Denis Compensator and of Main Valve.

of steam expanded between these limits of pressure is 65 per cent.

It has eleven wheels, of slightly varying diameter, the mean

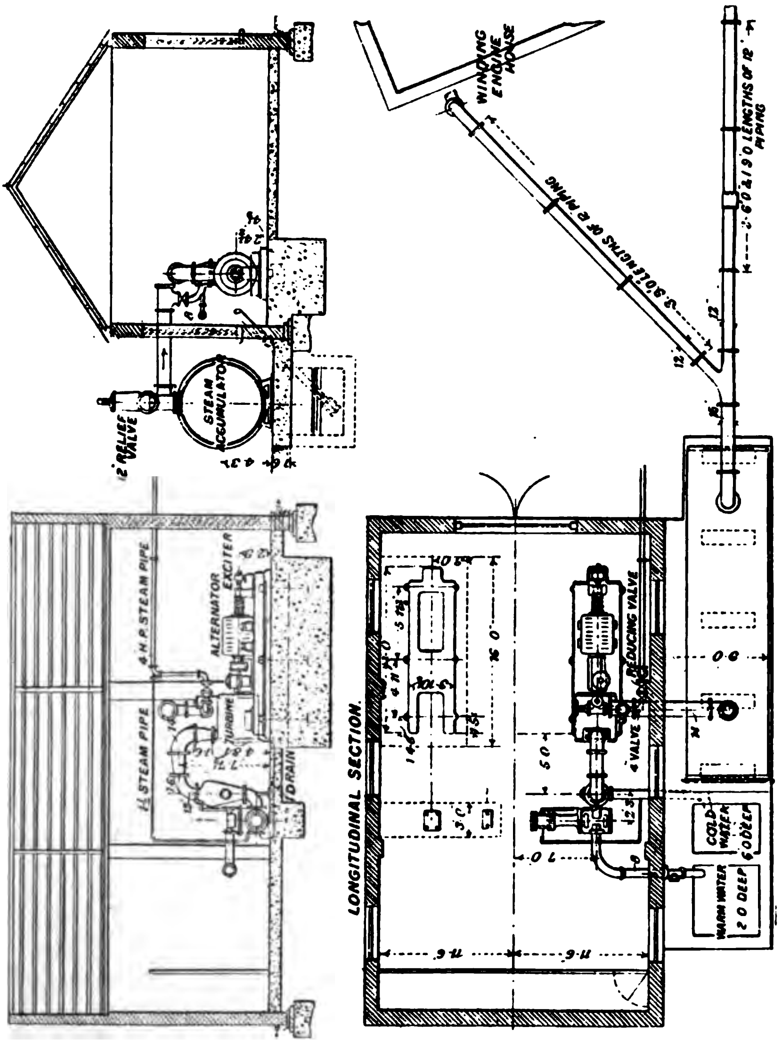


Fig. 172.—Rateau Plant at Hucknall Torkard Colliery, by Mr P. J. Mitchell.

being about 39·75 inches; the mean peripheral speed 80 metres per second.

The space occupied by the turbo-generator is 22 feet × 6 feet.

A photo of the accumulator is shown in Fig. 169, p. 253.

On stopping the main engines one turbine has run with the

live steam supply cut off for six minutes at a load of 1700 amperes, and at the end of nine minutes an output of 500 amperes was still given, the supply coming only from the accumulator, in which the pressure was reduced to 10 inch vacuum.

The accumulator was designed to give full load with engine stoppages of 40 seconds when both turbines are working.

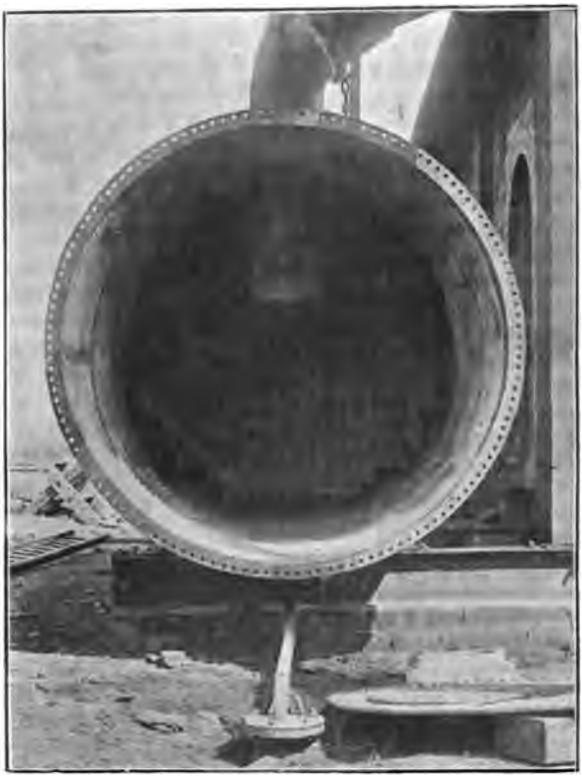


FIG. 173.—Interior of Heat Accumulator at Hucknall Torkard Colliery, showing the old rails used.

HUCKNALL TORKARD COLLIERY, NOTTINGHAM.

This plant is driven by a small part of the exhaust steam from a 36 inch × 6 foot stroke double cylinder winding engine.

About one fourth of the steam is used at full load in the turbine, the remainder blowing off at the relief valve. The steam exhausts from the winding engine for 12 seconds, and is then cut off for 40 seconds.

The plant being a small one, and sufficient scrap colliery train rails being available, the old rail type of accumulator was decided upon.

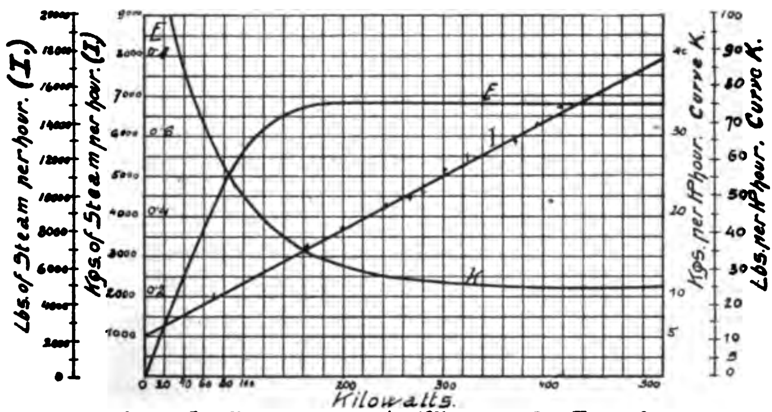
The accumulator shown in Fig. 172, at the side of the turbine-house, consists of an old boiler 6 feet diameter × 24 feet long, with 50 tons of old rails stacked, as shown in the photo Fig. 173.

The turbine is of 175 B.H.P. output at 3000 revolutions per minute, inlet pressure 14·7 lbs. absolute, and exhausting to 26 inch vacuum. It is direct-coupled to a 3-phase generator, 50 cycles per second, 500 volts.

The action of the accumulator is very regular, and the turbine behaves well under a load which is taken off and on about 50 times per hour, and varies from 130 per cent. to 15 per cent. of rated load. The speed varies about 4 per cent., and the voltage is well maintained under these conditions.

TABLE LXX.—TESTS ON STEEL CO. OF SCOTLAND'S LOW-PRESSURE TURBINE, JAN. 1906.

Reference Numbers.	Amps.	K.W.	Vacuum at Turbine's Exhaust.	Absolute Pressure. On entering Turbines.	Absolute Pressure. Exhaust.	Steam Consumptions. Total per hour.	Steam Consumptions. Per K.W.H.
			Ins.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs.	Lbs.
1	300	69	28·7	2·90	·5830	4,590	66·4
2	700	161	28·4	4·49	·7394	7,170	44·5
3	865	196·5	28·4	5·35	·7394	8,290	42·1
4	925	212·5	28·4	5·65	·7394	8,750	41·1
5	1050	241	28·4	6·11	·7394	9,480	39·3
6	1160	267	28·4	6·54	·7394	9,920	37·1
7	1120	278	28·6	6·68	·6399	10,250	36·8
8	1300	299	28·6	7·25	·6399	11,130	37·2
9	1400	322	28·6	7·82	·6399	12,080	37·5
10	1500	345	28·5	8·25	·6825	12,790	37
11	1600	368	28·4	8·25	·7394	12,800	34·8
12	1700	391	28·3	8·82	·7821	13,600	34·8
13	1800	414	28·2	9·53	·8247	14,500	35·1
14	1800	414	28·0	10·1	·9243	15,400	37·2
15	1900	437	27·9	10·7	·9811	16,300	37·3
16	1690	389	27·9	9·53	·9811	14,500	37·4
17	1825	420	27·9	9·95	·9811	15,300	36·4
18	1950	450	27·9	11·4	·9811	16,480	36·6



Curve E Thermodynamic Efficiency (See Fig. 236).

FIG. 173A.—Tests in Table LXX.

CHAPTER VII

THE ZOELLY STEAM TURBINE

In 1903, Messrs Escher Wyss & Co.[1] of Zurich undertook the manufacture of this type of turbine. In its design, the fall of pressure in the steam is confined to the fixed parts of the turbine, so that each revolving vane runs in a medium of almost uniform pressure.

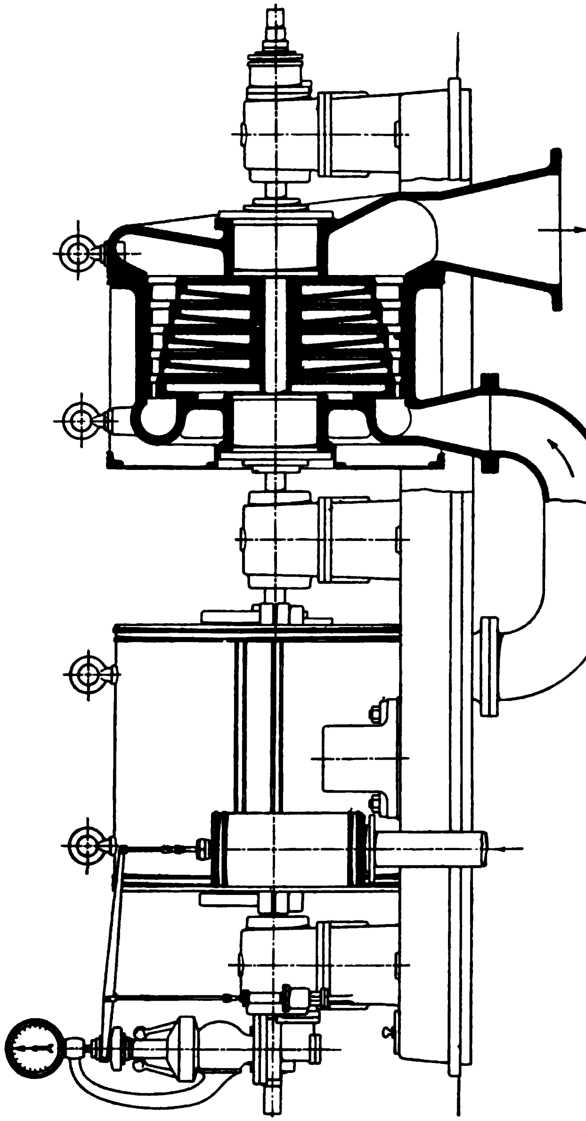
As in the Rateau turbine (and unlike the Curtis), all the kinetic energy developed in each fixed guide passage is utilised in a single revolving wheel.

The cylinders are fixed to the bed symmetrically, with a view to avoid warping due to heating. Each cylinder is divided in a horizontal plane through its centre, and the flanges are ground to a steam-tight metal-to-metal joint.

Vanes.—Nickel steel, carefully polished to reduce friction of the steam, is used to make the blades, which have their inner ends shaped to fit the dovetail formed of the wheel disc and the ring marked S in Fig. 175. Special steel distance pieces *g h*, similarly shaped, maintain the spacing between adjacent vanes. The ring S is screwed on after all the blades and distance pieces are in place. In plan (bottom of Fig. 175), the section of the vanes is shown. Each forms about a third of a complete cylinder, the two edges presenting equal angles.

A single piece of Siemens-Martin press-forged steel, shaped as shown in Fig. 175, forms each wheel disc. The thickness of disc and of blades tapers outwards, the determination of the

[1] The Siemens & Halske Co., Berlin; Bremer Maschinen und Armaturenfabrik, Bremen; Messrs Krupp & Sons, Essen; and Vereinigte Augsburger und Nürnberger Maschinenfabrik are at present engaged on production of the Zoelly Turbine.



"THE ENGINEER" SWAIN SC.

FIG. 174.—Part section Zoelly Turbine, 500 Horse-power, 3000 Revolutions per minute, 45-inch diameter wheel.

sections being based on Professor Stodola's calculations[1] to reduce centrifugal effects to a minimum.

[1] *The Engineer*, p. 556, June 3, 1904. Attention was called in *Engineering*, p. 771, June 3, 1904, to Parsons having patented in 1893, but without developing commercially, the use of low peripheral speed by splitting up the expansion into several stages and passing the steam, at speeds thus reduced to practical limits, through as many pairs of guide and revolving wheels as there are "steps" of expansion.

Diaphragms.—Fig. 176 shows the guide blade disc or diaphragm (made in halves, with a ground metal-to-metal joint between them) which carries the expanding nozzles or guide blades. The boss *r* surrounds the boss of the revolving wheel (Fig. 175, below), and is grooved internally (but there are no corresponding grooves shown on the revolving wheel), to reduce leakage to a minimum. The faces at *k* and *h*, Fig. 176, are machined, and successive diaphragms have face K of one, making a joint with *h* of the next. The revolving vanes run with clearance in the space near *k*. The outer part, lettered *h k*, is cast in one with the centre *r*, O_2, as

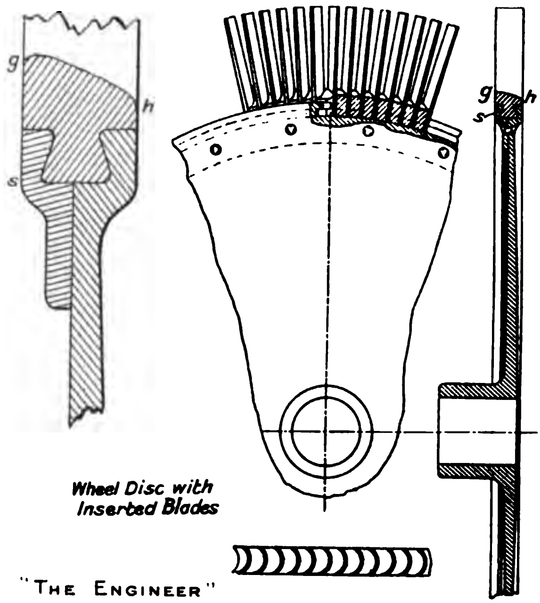


Fig. 175.—Revolving Wheel Disc with Blades inserted.

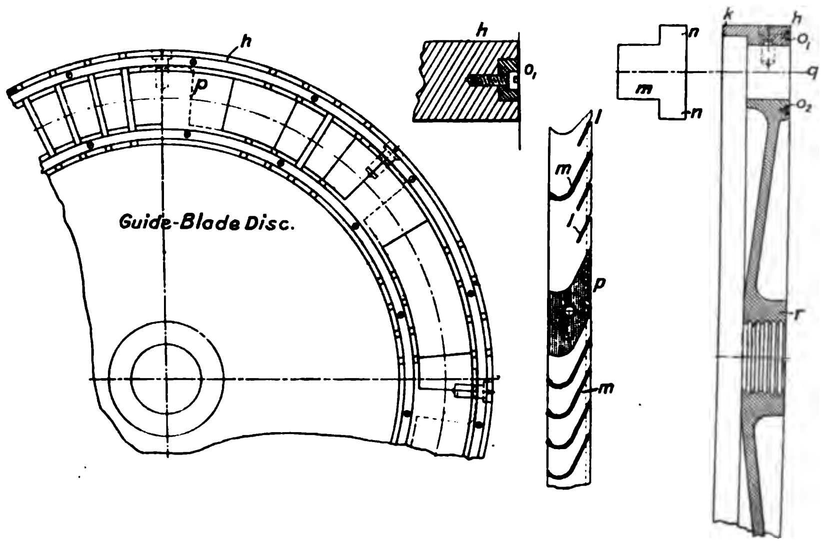
shown at *p p*. The guide passages and bridges *p p* make up the circumference. The bridges cover a larger arc in the high-pressure end of the turbine (*i.e.* admission is limited to a small arc). One of the guide blades is shown flat at *m*, *n*, *n*, Fig. 176, and several shaped in place at *m* in section in the same Figure. Oblique slots *l l* are shown in the outer rim *h* and inner rim at O_2, and the projections *n n* on each blade fit into these slots, and over them are screwed the rings O_1, O_2, sunk in groves turned for them.

Governor.—A centrifugal governor and an auxiliary oil cylinder control the speed. An accumulator, fed from the rotary pump which supplies the bearings, provides oil pressure

through the supply pipe lettered *a* in Fig. 177. If the speed rises, lever *n* raises valve *m*, which admits oil through pipe *f* to the top of cylinder *h*, and also discharges oil from the other end of that cylinder through pipes *e* and *b*. This drives the throttle *k* down, and the lever *n* now lowers valve *m* to its mid position, stopping the supply of oil.

Emergency Governor.—An adjustable independent governor set to act at about 10 per cent. above normal speed, closes the regulating valve by means of a spring.

Bearings.—The bearings in the 500 horse-power size (370



"THE ENGINEER" SWAIN Sc

FIG. 176.—Diaphragm or Guide Blade Disc.

kilowatt) are three in number, and mounted independent of the cylinders, so they are accessible.

In the Nonnendamm machine, Fig. 179, there are two intermediate bearings, with a coupling between them joining the shaft, which is made in two parts.

Thrust Bearing.—A thrust bearing is provided to control the setting of the revolving vanes.

Oiling.—A small rotary pump on the bed plate, driven by helical gear off the main shaft, forces oil into the bearings, and returns it to a tank in the bed plate through a series of cooling tubes and a filter.

In the tests quoted in Table LXXII. and curves Fig. 180 the oil was supplied at 30° to 35° C., and flowed away at 40° to 50° C.

Glands.—Grooved metallic packing is used where the shaft passes through the end of a cylinder.

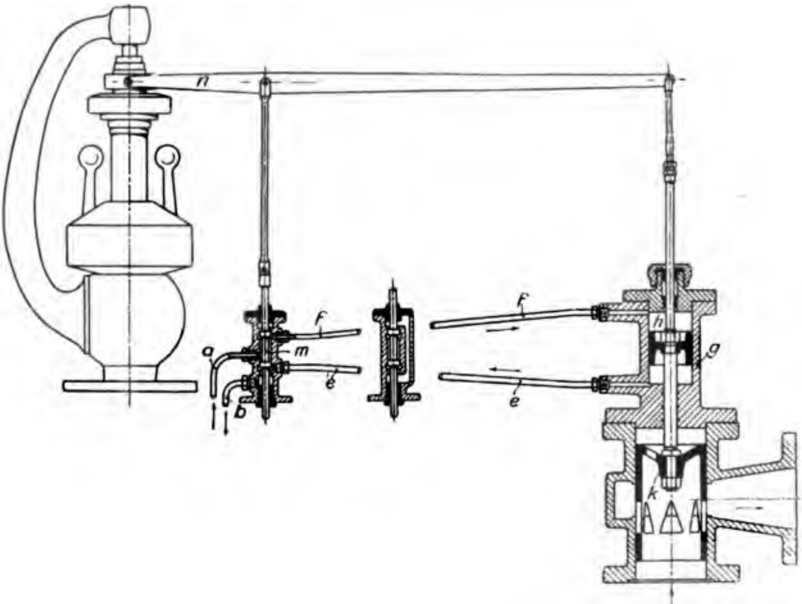


FIG. 177.—Governor (with Throttle in section).

a, supplies oil under pressure. *L*, auxiliary oil cylinder.
b, returns oil. *k*, steam throttle.

See also Fig. 174.

TABLE LXXI.

The speeds standardised by Messrs Escher Wyss & Co. are—

KW.	R. P. M.	KW.	R. P. M.
340	3000	1350	1800
475	„	1700	1500
675	1500	2000	„
1000	„	2600	1200

The 500 H.P. (370 K.W.) unit has (Table LXXII., Fig. 180)—

Maximum diameter revolving ...	45 inches
Revolutions per minute	3,000
Peripheral speed	35,360 ft. per minute
„ „ nearly	600 ft. per second
Number of Pressure steps	10
„ „ Revolving wheels ...	10
„ „ Blades per wheel ...	132
Generator 3-phase	600 volts
Pressure	
Output per blade	0·3 K.W.

The Managing Director of Messrs Escher Wyss & Co., Zurich, Switzerland, and Ravensburg, Germany, has kindly placed at our disposal the tests previously[1] published, together with some

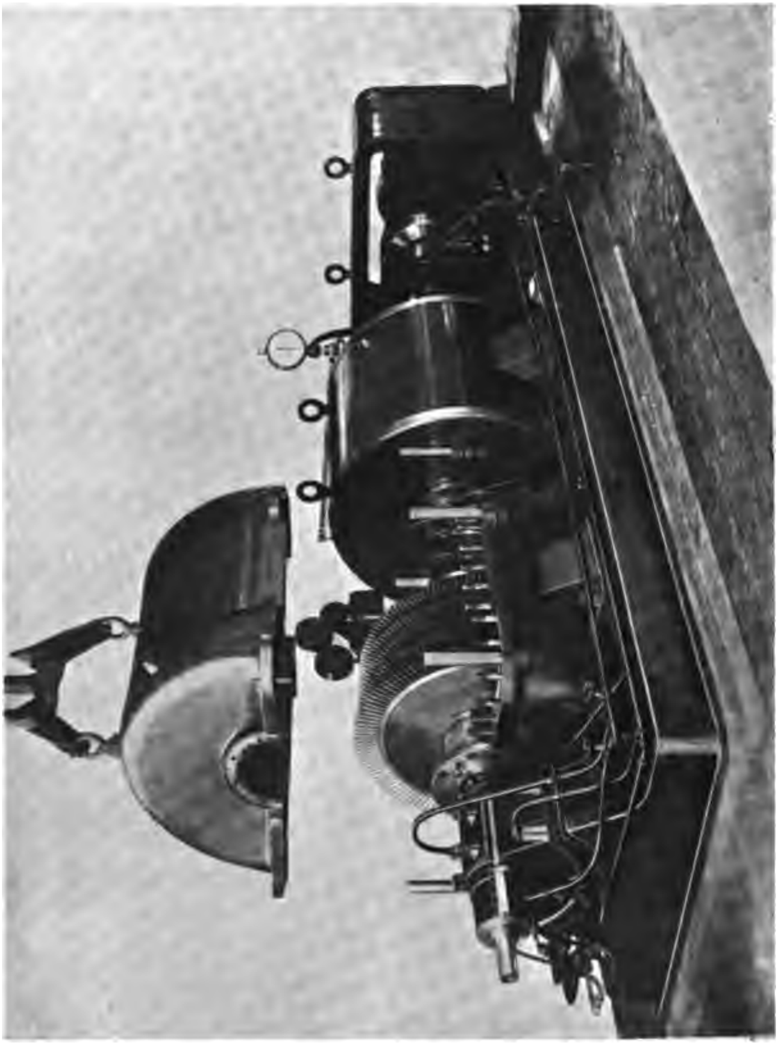


Fig. 178.—Zoelly Turbine with one Cylinder Cover raised. 500 Horse-power. *(Photo supplied by Messrs Escher Wyss & Co.)*

later tests and illustrations of the machines which he has designed, and which are known by his name.

[1] Stahl und Eisen, Number 18, 1904, by J. Weishäupl. *Zeitschrift des Vereines deutscher Ingenieure*, 1904. *Engineering* and *The Engineer*, June 3rd, 1904. Stodola's *The Steam Turbine.*

TABLE LXXII.—TESTS OF 500 H.P. ZÖLLY TURBINE DRIVING

		Saturated Steam.							
	Test Number	1.	2.[1]	3.	4.	5.	6.	7.	8.
Percentage of Rated Load 870 K.W.	Per cent.	99	105	91	65	50	22	zero	zero
Date of Test		21D 03	25Ja.04	25Ja.04	25Ja.04	25Ja.04	18Ja.04	25Ja.04	25Ja.04
Time of start		3 hr. 10	3 hr. 15	3 hr. 55	2 hr. 45	1 hr. 30	4 hr. 00	11 hr. 25	10 hr 35
Time finished		6 hr. 10	4 hr. 35	4 hr. 45	3 hr. 35	2 hr. 20	5 hr. 00	12 hr 25	11 hr 10
Duration of Test	Minutes.	180	80	50	50	50	60	60	35
Total power	K.W.	363·78	388·47	335·31	240·78	182·85	80·62	..	..
Excitation, volt amperes	K.W.	0·72	0·82	0·80	0·68	0·63	0·49	0·497	..
Useful power (subtracting excitation, but not subtracting work of air pump)[2]	K W.	363·06	387·65	334·51	240·1	182·22	80·13	excited	not excited
No. of revolutions	Per minute.	2 967	2 967	2 977	2 983	2 984	2 995	2 995	3 000
At Entrance to Separator:									
Pressure	Atm. abs.	11·16	11·16	10·90	11·01	10·97	11·04	11·03	11·19
	Lbs. per sq. in. abs.	164·0	164·0	160·2	161·8	161·2	162·26	162·1	164·5
Temperature	° C.	187·2	187·6	184·7	185·3	185·1	184·9	184·9	185·7
	° *F.*	369·0	369·7	364·5	365·5	365·2	364·8	364·8	366·3
Temp. of saturation	° C.	183·7	183·7	182·6	183·1	182 9	183·2	183·15	183·8
	° *F.*	362·7	362·7	360·7	361·6	361·2	361·8	361·67	362·8
Superheat	° C.	3·5	3·9	2·1	2·2	2·2	1·7	1·8	1·9
	° *F.*	6·3	7·0	3·8	4·0	4·0	3·1	3·2	3·4
At Entrance to First Guide Wheel:									
Pressure	Atm. abs.	(10·1) ?	10·11	9·03	6 92	5·47	3·07	1·22	0·747
	Lbs. per sq. in. abs.	(148·4)?	148·6	132·7	101·7	80·39	45·12	17·93	10·98
Temperature	° C.	179·9	180·0	175·1	164·9	156·6	136	106·8	102·9
	° *F.*	355·8	356·0	347·2	328·8	313·9	276·8	227·8	217·2
Temp. of saturation	° C.	178·9	179·4	174·5	163·6	154 4	133·6	104·7	91·2
	° *F.*	354·0	354·9	346·1	326·5	309·9	372·5	220·5	196·2
Superheat	° C.	1·0	0·6	0·6	1·3	2·2	2·4	4·1	11·7
	° *F.*	1·8	1·1	1·1	2·3	4·0	4·3	7·4	21·1
Pressure at exit from 1st guide wheel	Atm. abs.	6·03	6·32	5·59	4·29	3·44	1·84	0·652	0·383
	Lbs. per sq. in. abs.	88·62	92·89	82·16	63·05	50·56	27·04	9·582	5·629
Pressure in connecting pipe	Atm. abs.	1·068	1·11	0·982	0·739	0·58	0·32	0·197	0·176
	Lbs. per sq. in. abs.	15·7	16·31	14·43	10·86	8·524	4·703	2·895	2·587
Pressure in exhaust pipe	Atm. abs.	0·0715	0·0721	0·0679	0·0657	0·0661	0·0521	0·051	0·0514
	Lbs. per sq. in. abs.	1·051	1·059	0·9979	0·9656	0·9714	0·7656	0·7495	0·7554
Temp. in Exhaust Pipe	° C.	39·1	39·9	38·9	37·1	36·6	32·7	32·2	42·1
	° *F.*	102·4	103·8	102·0	98·8	97·9	90·9	90·0	107·8
Pressure in condenser	Atm. abs.	..	0·046	0·0471	0·051	0·053	0·044	0·044	0·046
	Lbs. per sq. in. abs.	..	0·6761	0·6921	0·7495	0·7789	0·6467	0·6467	0·6761
Temp. of condensed steam: Pipe	° C.	22·5	22·4	22·2	22·8	24·1	..	16·5	16·5
Tank	° C.	23·9	23·9	24·8	26·2	26·8	23·6	26·2	27·1
Pipe	° *F.*	72·5	72·3	72·0	73·0	75·4	..	61·7	61·7
Tank	° *F.*	75·0	75·0	76·6	79·2	80·2	74·5	79·2	72·8
Barometer reading	Mm. mercury.	736	731	730	730	730	733	730	731
Total steam consumption per hour	Kg.	3 585	3 776·6	3 368·5	2 621·0	2 124·2	1 202·0	465·0	295·4
	Lbs.	7 903·5	8 325·8	7 426·4	5 778·4	4 682 6	2 649·9	1 025·2	6 51·24
Steam consumption per useful K.W. hour	Kg.	9·874	9 742	10·070	10·916	11·657	15·00	..	..
	Lbs.	21·768	21·477	22·201	24·065	25·699	33·069	..	..
Theoretical steam consumption per K.W. referred to condition of steam at entrance to steam separator and vacuum in exhaust pipe	Kg.	4·885	4·887	4·873	4·835	4·85	4·702	..	..
	Lbs.	10·769	10·774	10·743	10·659	10·692	10·366	..	..
Steam consumption per B.H.P. hour	*Lbs.*	13·9	14·0	14·1	15	15·6	18·1	..	..
Thermodynamic efficiency	Per cent.	52·3	50·2	48 4	44·3	41·6	31·3	..	..

[1] Unless tests covered periods of day and of night there are errors probably in the dates. Test 2 overlaps 3 and 4. The no-load test No. 8 is stated to have been taken during the 243 K.W. test No 11.

A SIEMENS & HALSKE THREE-PHASE GENERATOR.

Variable Number of Revolutions.							Poor Vacuum.		With Superheated Steam.			Poor Vacuum.
Low Power.			Normal Power.									
9.	10.	11.[2]	12.	13.	14.	15.	16.	17.	18.	18a.	19.	20.
80	76	66	106	109	109	102	79	86	106	106	106	83
26Ja.04	26Ja.04	25Ja.04	26Ja.04	26Ja.04	26Ja.04	26Ja.04	26Ja.04	26Ja.04	5 F. 04	5 F. 04	5 F. 04	5 F. 04
1 hr. 45	11 hr. 35	10 hr. 10	4 hr. 50	5 hr. 02	5 hr. 15	5 hr. 32	5 hr. 55	6 hr. 19	3 hr. 50	3 hr. 50	11 hr. 15	5 hr. 35
2 hr. 35	12 hr. 35	11 hr. 10	4 hr. 55	5 hr. 12	5 hr. 23	5 hr. 42	6 hr. 10	6 hr. 30	5 hr. 00	4 hr. 10	12 hr. 35	5 hr. 45
50	60	60	5	10	8	10	15	11	70	20	80	10
296·4	280·03	243·15	397·4	400·6	404·4	375·2	289·25	319·42	392·5	390·41	391·2	306·21
0·498	0·511	1·09	(0·8)	(0·7)	(0·5)	(1·1)	(0·55)	0·74	0·81	0·806	0·816	0·78
295·9	279·52	242·06	(396·6)	(399·9)	(403·9)	(374·1)	288·7	318·68	391·66	389·6	390·4	305·43
3 229	2 430	1 890	3 048	3 122	3 229	2 649	2·982	2 982	2 972	2 973	2 968	2 960
11·12	10·61	11·00	10·87	11·03	11·13	10·71	10·54	10·48	11·81	13·13	11·26	(10·23)
163·4	155·9	161·7	159·8	162·1	163·6	157·4	154·9	154·0	188·3	193·0	165·5	(154)
186·5	188·2	192	189·1	190·0	190·6	184·9	184·6	183·7	247·1	258·5	226·6	247·7
371·3	370·8	374·4	372·4	374·0	375·1	364·8	364·3	362·7	476·8	497·3	439·9	477·9
183·5	181·57	183·05	182·5	183·15	183·68	181·9	181·2	180·95	189·95	191·02	184·1	179·9
362·3	358·83	361·49	350·5	361·67	362·62	359·4	358·2	357·71	373·91	375·84	363·4	355·8
5·0	6·7	7·2	6·6	6·9	7·0	3·0	3·4	2·8	57·2	67·5	42·5	67·8
9·0	12·1	13·0	11·9	12·4	12·6	5·4	6·1	5·0	103·0	121·5	76·5	122·0
7·96	7·96	7·96	10·08	10·08	10·08	10 06	9·41	9·48	9·72	9·72	9·80	9·43
117·0	117·0	117·0	148·1	148·1	148·1	148·1	138·3	139·3	142·9	142·9	144·0	138·6
171·2	172·0	172·2	180	180·1	180·2	179·2	176·7	176·9	216·5	219	216·5	224·5
340·2	341·6	342·0	356·0	356·2	356·4	354·6	350·1	350·4	421·7	426·2	421·7	436·1
169·2	169·2	169·2	179·2	179·2	179·2	179·2	176·3	176·6	177·6	177·6	178·0	178·9
336·6	336·6	336·6	354·6	354 6	354·6	354·6	349 3	349·9	351·7	351·7	352·4	354·0
2·0	2·8	3 0	0·8	0·9	1·0	0·0	0·4	0·3	38·9	41·4	38·5	45·6
3·6	5·0	5·4	1·4	1·6	1·8	0 0	0·7	0·5	70 0	74·5	69·3	82·1
4·76	4·95	4·95	6·36	6·34	6·30	6·35	5 93	6·0	6·23	6·212	6·28	6·15
69·95	72·75	72·75	93·48	93·17	92·56	93·33	87·16	88·18	91·56	91·30	92·30	90·39
0·84	0·87	0·862	1·12	1·14	1·15	1·12	1·05	1·06	1·07	1·056	1·09	1·06
12·35	12·78	12·69	16·46	16·75	16·90	16·46	15·43	15·58	15·73	15·52	16·02	15 58
0·0683	0·0665	0·0682	0 ·0696	0·0695	0·0692	0·0690	0·1922	0·137	0·0653	0·0664	0·0692	0·213
1·004	0·9772	1·002	1·023	1·021	1·023	1·014	2·825	2·013	0·9596	0·9759	1·017	3·130
38·5	38·0	38·5	39·6	39·5	39·1	39·2	59·3	51·8	38·0	38·8	38·0	61
101·3	100·4	101·3	103·3	103·1	102·4	102·6	138·7	125·2	100·4	101·8	100·4	141·8
0·051	0·046	0·048	..	..	..	..	..	..	0·040	0·042	0·042	0·203
0·7495	0·6761	0·7053	..	..	..	..	..	..	0·5879	0·6172	0·6172	0·2983
23·3	21·8	21·1	..	..	..	..	..	..	20·2	20·5	20·4	44·25
25·3	23·2	23·3	..	..	..	..	..	..	22·4	22·4	23·7	34·15
73·9	71·2	70·0	..	..	..	..	..	..	68·4	68·9	68·7	111·65
77·5	73·8	73·9	..	..	..	..	..	..	72·3	72·3	74·7	93·47
731	731	731	731	731	731	731	731	731	715	715	715	715
2 980·1	2 978·4	2 974·9	(3 770)	(3 770)	(3 770)	(3 770)	(3 500)	(3 516)	3381·1	3327·0	3 505·7	(3 225)
6 569·9	6 566·1	6 558·6	(8 311·3)	(8 311·3)	(8 311·3)	(8 311·3)	(7 716·2)	(7 751·4)	7 454 0	7 334·7	7 728·8	(7 109·8)
10·07	10·653	12·29	(9·50)	(9·43)	(9·33)	(10·08)	(12·12)	(11·03)	8·633	8·339	8·98	(10·56)
22·20	23·486	27·094	20·94	20 79	20·57	22·222	26·719	24 317	19·032	18·384	19·797	23·281
4·825	4·876	4·846	4·867	4·855	4·843	4·897	5·87	5·60	4·46	4·41	4·683	5·642
10·637	10·749	10·683	10·730	10·703	10 677	10·796	12·941	12·346	9·838	9·722	10·324	12·438
..	..	..	..	..	..	..	..	..	..	..	..	..
47·9	45·8	39·4	(51·2)	(51·5)	(51·8)	(48·5)	(48·4)	(50·8)	51·7	51·3	52·2	(53·4)

[2] The circulating and air pumps were estimated to consume 3 per cent. of normal power.

FIG. 179.—Zoelly Turbine for Power Station, Nonnendamm, Berlin.
(*Photo supplied by Messrs Escher Wyss & Co.*)

TABLE LXXIII.—TESTS, ZOELLY TURBINE 405 K.W.

Date of Test, May 1904.	Moderate Superheat.		Higher superheat.	
1. Load	Full	½ load	Full	½ load
2. Duration of Test minutes	30	50	50	30
3. Revolutions per minute	3187	3214	3139	3254
Before the admission valve—				
4. Pressure *absolute* kg. per sq. cm.	11·25	11·70	11·56	11·80
„ *lbs. per sq. inch*	160	166	164	168
5. Temperature °C.	235	236·5	284	271·5
„ °*F.*	455	458	543	521
6. Temperature of saturated Steam °C.	184	185·8	185	186
Temperature of saturated steam °*F.*	364	366	365	366
7. Superheat (5–6) °C.	51	50·7	99	85
„ „ °*F.*	92	91·5	179	153
8. Vacuum in cm. of mercury (33° C.)	68·3	68·6	68·6	68·6
9. Vacuum in cm. reduced to 0°C.	67·9	68·2	68·2	68·2
Inches	26·6	26·8	26·8	26·8
10. Barometer mm. of mercury at °C.	728 at 20°	728	729 at 18½°	729
11. Barometer mm. reduced to 0°C	725	725	727	727
Inches	28·5	28·5	28·6	28·6
12. Pressure in exhaust pipe to condenser *absolute* kg. per sq. cm.	0·062	0·06	0·061	0·061
Lbs. per sq. inch	·88	·85	·87	·87
13. Output in K.W.	414	197	405	197
Steam consumption—				
14. Per hour, kgs.	3500	2000	3220	1870
„ „ *lbs.*	7700	4400	7100	4120
15. Per K.W. Hour kgs.	8·46	10·14	7·97	9·51
„ „ „ *lbs.*	18·7	22·4	17·6	21·0

TABLE LXXIV.—ACCEPTANCE TESTS, 475 K.W. ZOELLY TURBO-GENERATOR FOR JOHANNISBURG.

Date.	February 23, 1905.		February 24, 1905.	
Load K.W.	249·9	462·7	425·2	255·1
Speed R.P.M.	3020	3010	3005	3045
Pressure at admission atmospheres *absolute* (at 14·22)	11·17	11·0	10·3	11·2
Lbs. per sq. inch absolute	159	157	147	160
Temperature °C.	185	184·7	260	263
Pressure in front of 1st set of nozzles. *Absolute* atmosphere	4·76	7·95	2·65	4·67
Lbs. per sq. inch absolute	68	100	109	66
Vacuum per cent.	92·52	91·8	92·4	93·2
Inches of mercury	27·8	27·5	27·6	28
Steam consumption kg. per hour	2879	4750	4128	2542
„ „ kg. per K.W. hour	11·51	10·25	8·68	9·96
Lbs. „ „ „	25·4	22·6	19·1	22

Constant Speed and Different Loads.—Tests, January 25th, 1904, were taken in this order, 8, 7, 5, 4, 3, as the times of starting show. Fewer significant figures in results of tests probably

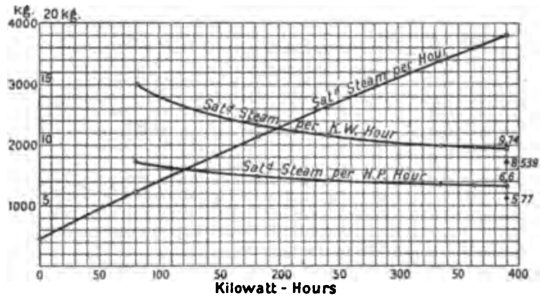


FIG. 180.—Zoelly Curves, from Table LXXII. *See* Table for English Units.

accord with the degree of accuracy of the instruments used and with the scale of the plotted curves. These results are plotted in Fig. 180.

TABLE LXXV.—405 ZOELLY TURBINE GENERATOR. ACCEPTANCE TEST AT THE POWER STATION, MÜHLHAUSEN, THÜRINGEN, GERMANY. (Fig. 181.)

Date.	Feb. 26, 1905.	Feb. 27, 1905.			
Load K.W.	**132·19**	**208·21**	**291·52**	**391·13**	**463·22**
,, B.H.P.	232·52	34·09	465·65	605·55	707·59
Dynamo efficiency [estimated thus: $\frac{\text{K.W.}}{736 \text{ B.H.P.}}$]	·775	·83	·87	·875	·89
Speed R.P.M.	**3061**	**3050**	**3040**	**3030**	**3020**
Pressure at admission atmospheres absolute (*at 14·22*)	**8·63**	**8·48**	**8·51**	**8·50**	**8·53**
Lbs. per sq. inch	123	121	121	121	121·5
Temperature °C.	**170·6**	**170·5**	**170·4**	**170·3**	**170·5**
Pressure in front of 1st set of nozzles. Atmosphere absolute	**2·71**	**3·8**	**5·0**	**6·53**	**7·61**
Lbs. per sq. inch	38·6	59	71	93	108
Vacuum per cent.	95·3	**94·5**	93·7	92·7	91·7
Steam consumption per hour: kgs.	**1870**	**2482**	**3240**	**4156**	**4819**
,, lbs.	4130	5500	7150	9200	10600
Per K.W. Hour: kgs.	**14·14**	**11·92**	**11·11**	**10·63**	**10·40**
,, lbs.	31·2	26·4	24·6	23·6	23
Per H.P. hour: kgs.	**8·04**	**7·09**	**6·96**	**6·86**	**6·81**
,, lbs.	17·7	15·6	15·4	15·1	15
Thermodynamic efficiency	**45·4**	**51·6**	**53·4**	**55·3**	**56·4**

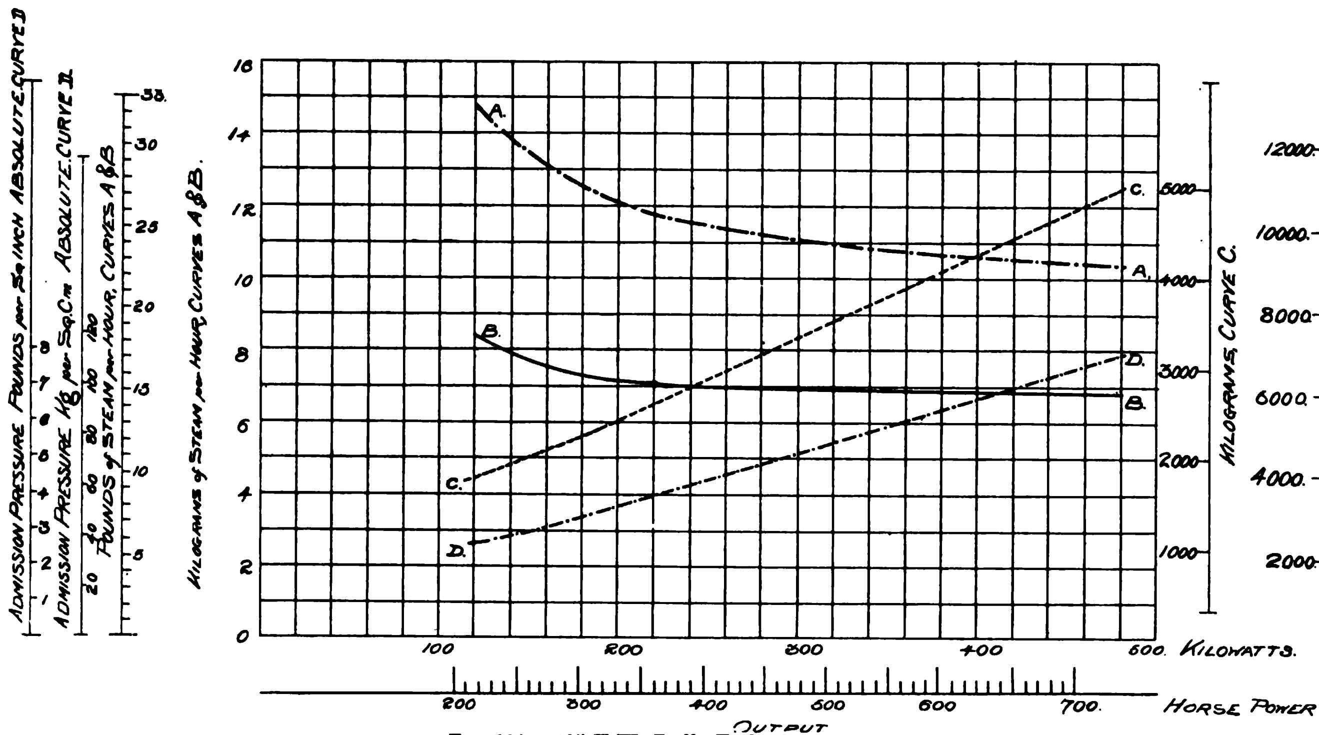


Fig. 181.—405 K.W. Zoelly Turbo-Generator Set.
(350 *K.W.* 250 *Volt supplying Lights.*)
(105 ,, 550 ,, *Tramway.*)

Tests at Power House, Mühlhausen, Thuringen, Germany, Feb. 26, 27, 1905. *See Table LXXII.*

Curve A = *Steam Consumption per K.W. Hour.*
,, B = ,, ,, *B.H.P.* ,,
,, C = *Total Steam.*
,, D = *Admission Pressure (Absolute.)*

Constant Pressure and Variable Speed.—Tests 9, 10, and 11 show constant total steam consumption with speed from 7 per cent. above normal (3000) at 80 per cent. of rated load to speed 63 per cent. of normal at 66 per cent. of rated load.

More recent tests, May 1904, on the same 405 K.W. Zoelly turbo-generator, with different amounts of superheat, are on p. 269.

Zoelly Marine Turbines.—The Zoelly turbine is to develop the motive power for the 500 ton (displacement) vessel now being tested by Messrs Howaldt, Kiel, for the German merchant marine. This vessel will have three shafts, and will develop 1000 to 1200 horse-power.

CHAPTER VIII

THE RIEDLER-STUMPF TURBINE

FROM Table XXV. on p. 40 we find that the largest de Laval turbine is rated at 300 horse-power.[1] The turbine wheel runs at 10,500 revolutions per minute, and has a diameter, measured from the middle of the blades, of 0·76 metres. This gives a peripheral speed of 420 metres per second, which is sufficiently high to constitute some approach to half the velocity of the impinging steam. The speed of 10,500 revolutions per minute, however, necessitates the use of reduction gearing to obtain practicable speeds for dynamos to be driven by the turbines. Could the speed of the turbine wheel be reduced to, say, 3000 revolutions per minute, the direct driving of alternating current dynamos without the intervention of reduction gearing would become practicable in certain cases, although half this speed, and even much less, would be of great advantage, more especially for sets of large capacity. In order to retain the peripheral speed of 420 metres per second it would be necessary for a 3000 revolutions per minute wheel to have a diameter of $\frac{10{,}500}{3{,}000} \times 0{\cdot}76 = 2{\cdot}66$ metres.

The centrifugal force at the rim would then be inversely as the diameters, or $\frac{0{\cdot}76}{2{\cdot}66} \times 47 = 13{\cdot}4$ metric tons per kilogram weight of material at the periphery, as against 47 tons for the smaller wheel.

Such proportions as these have been employed in the Riedler-Stumpf type of steam turbine, and by thus avoiding the necessity for speed reduction gearing, they have been able to build sets of very large capacity. Except for the use of far larger diameters

[1] With the exception of the 350 horse-power design listed by the Société de Laval of France, of which we have no particulars.

and the avoidance of speed reduction gearing, the simpler types of Riedler-Stumpf turbine involve the same general principles as those

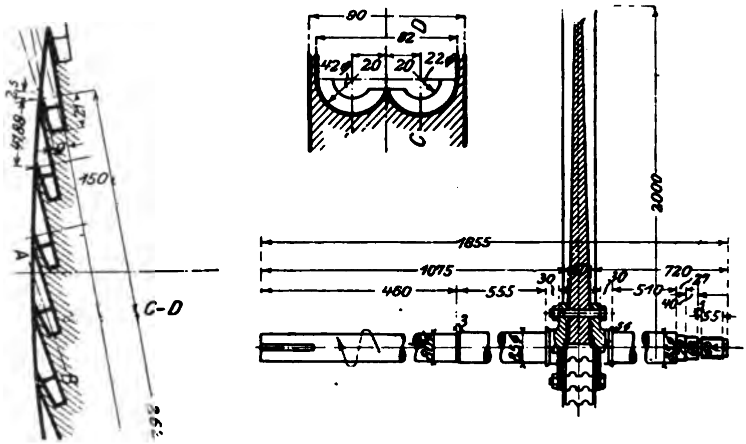


Fig. 182.—Riedler-Stumpf 2000 Horse-power Wheel.

employed in the de Laval type, although in details of design and construction many interesting and novel features are introduced.

Fig. 183.—Riedler-Stumpf 2000 Horse-power Wheel.

Figs. 182, 183, and 184 illustrate the wheel of a 2000 horse-power (2000 × 0·736 = 1475 kilowatt) Riedler-Stumpf turbine.

It runs at 3000 revolutions per minute and has a diameter of 2 metres. Thus the peripheral speed is 314 metres per second.

The centrifugal force at the periphery at 3000 revolutions per minute is $0{\cdot}00000559 \times 200 \times 3000^2 = 10{,}100$ kilograms per kilogram, or about 10 metric tons for every kilogram of material at the periphery.

The construction of the hub should be particularly noticed.

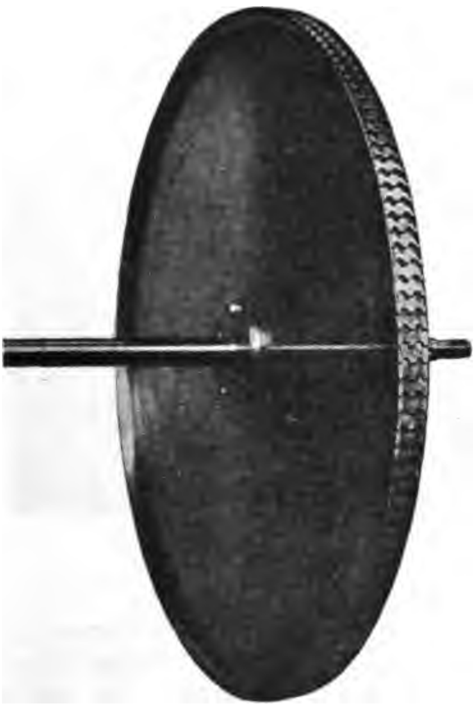


FIG. 184.—Double Buckets.

FIG. 185.—Single Buckets.

Were it bored at the centre the wheel would be greatly weakened, consequently the shaft is attached by bolts as shown, the holes for the bolts being at such a distance from the centre as not to seriously affect the strength of the wheel. A 10 per cent. nickel steel was employed for the wheel above illustrated.

In some of the multiple stages types which superseded the original single-wheel Riedler-Stumpf type, it was impracticable to avoid boring the centre of the wheel for the reception of the shaft.

Such a case is shown in Fig. 186, and it will be seen that the hub is gradually increased in thickness toward the centre, as in the de Laval type, for the purpose of decreasing the otherwise abnormal stresses in the material at this point.

The nickel steel employed for the wheel of the Moabit 2000 horse-power turbine has a breaking strength of 9500 kilograms per square centimetre and an elastic limit of 7500 kilograms per square centimetre. The buckets were milled in the rim of the wheel. There are 150 buckets on the periphery, the pitch thus being about 42 millimetres. Each bucket is double (see Figs. 182 to 184), and the output per half-bucket is $\frac{1475}{2 \times 150} = 4{\cdot}9$ kilowatts, a far higher value than is customary in other steam turbines. An

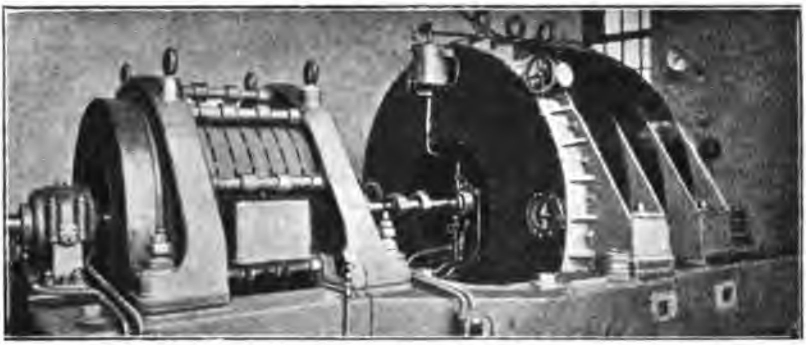


FIG. 186.—Riedler-Stumpf Moabit Set.

alternating current dynamo of 1475 kilowatts rated capacity is driven from this turbine, and the set is installed at the Moabit Central Station of the Berlin Electrical Works. The set is illustrated in Fig. 186.

From some published descriptions of this set it would be inferred that no outer bearing has been provided for the turbine wheel, and that it is overhung as indicated in Fig. 187, the wheel hub construction being that indicated in Fig. 188.

By a careful study of the descriptions, however, this appears not to be the case, and the construction indicated in Fig. 187 is apparently an alternative design for the same rating, *i.e.* 2000 horso-power and 3000 revolutions per minute. In the case of the Moabit set an outer bearing was employed.

The maximum stress in the wheel shown in Figs. 182 to 184

amounts to 1900 kilograms per square centimetre, the factor of safety thus being $\frac{9500}{1900}$ or 5. It has been proposed in later designs of this type to employ forged steel, with a breaking strength of 5000 kilograms per square centimetre. This would, on one hand, reduce the factor of safety to about 2·5, but the material could probably be relied upon to be more uniform than nickel steel. As, however, the stress increases as the square of the speed, the wheel, if it had a factor of safety of only 2·5, would

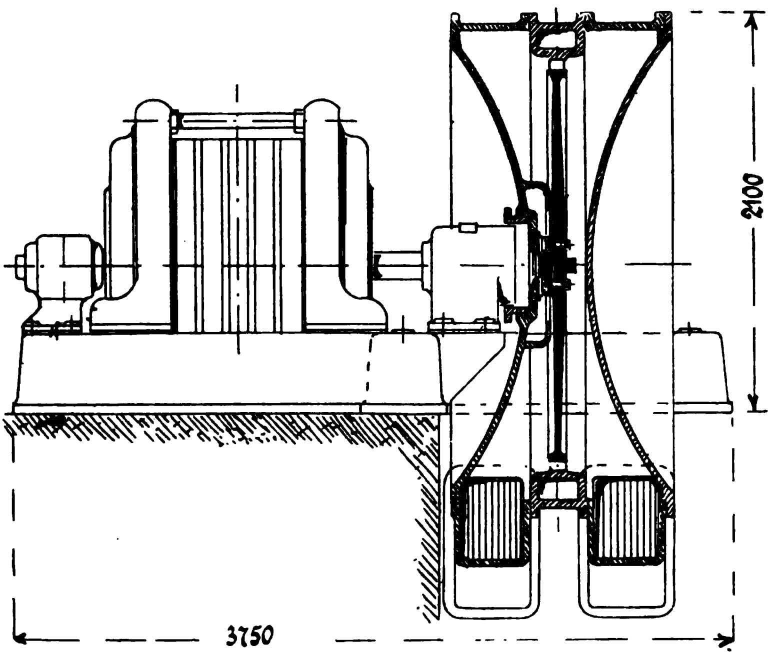


FIG. 187.—Riedler-Stumpf Turbine 2000 Horse-power, 3000 R.p.m.

burst at a speed some 60 per cent. in excess of the rated speed. Hence, so low a factor of safety would not be sufficient if the speed regulator and the safety governor both failed, in which case a speed of, say, double the rated speed might be attained by the wheel, although the rapidly increasing friction of the wheel, of the bearings, and especially of the rotor of the direct connected dynamo would make so great an increase in speed less probable than would appear to be the case from a mere consideration of the relative speeds of the steam and the buckets. The greatest stresses in the Riedler-Stumpf wheel are not in the rim, but on a

section near or at the axis, and hence, should a wheel burst, the destruction occasioned not only to the turbine but to surrounding property would equal or exceed that accompanying the bursting of fly wheels. On the contrary, as explained in Chapter III., the breaking of a de Laval wheel is a trifling matter. In a Parsons turbine the stresses are far more moderate, owing to the lower peripheral speeds.

The nozzles discharge jets of steam in the plane of the wheel instead of from the side as in the de Laval design, and this is claimed to have the advantage of avoiding all axial thrust. In the design illustrated in Figs. 182 to 184 the steam, in impinging on the rim of the wheel, is divided into two streams, in virtue of the

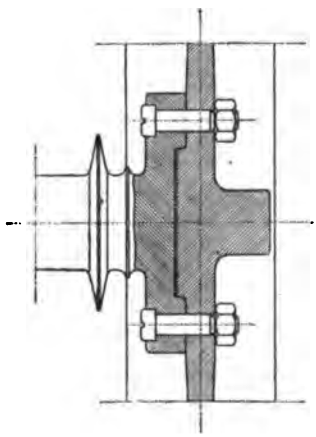


FIG. 188.—Wheel Hub.

double design of the buckets. These two streams flow to the right and to the left respectively. In another design illustrated in Fig. 185 there is but one row of single buckets.

In the 2000 horse-power Moabit set there is a radial clearance of 3 millimetres between the ends of the nozzles and the periphery of the wheel. Measured in the direction of the axis of the nozzle, the clearance is about 10 millimetres. As the expansion of the steam is completed in the nozzle (as in the de Laval type), a considerable clearance occasions no loss or diminution in capacity, and this is stated to have been shown experimentally to be the case for the Riedler-Stumpf type when the radial clearance was increased from 3 millimetres to 5 millimetres.

The wheel is highly polished, with a view to decreasing the

friction; and the overlapping arrangement of the buckets, as will best be seen from Fig. 183, is such as to give a considerably less resistance for a given peripheral speed than would be the case with radially projecting blades.

It is stated that the manufacture of the Riedler-Stumpf wheel is so exact as to permit of their being balanced with such precision that the centre of gravity is well within 0·1 millimetre of the axis of rotation. This exactness avoids the necessity for employing a flexible shaft.

The turbine wheel of the 2000 horse-power Moabit machine is stated to weigh about 850 kilograms, or 0·58 kilogram per kilowatt output. Assuming that this weight does not include the shaft, it may be readily deduced that the wheel has an average thickness of about 3·5 centimetres. This appears con-

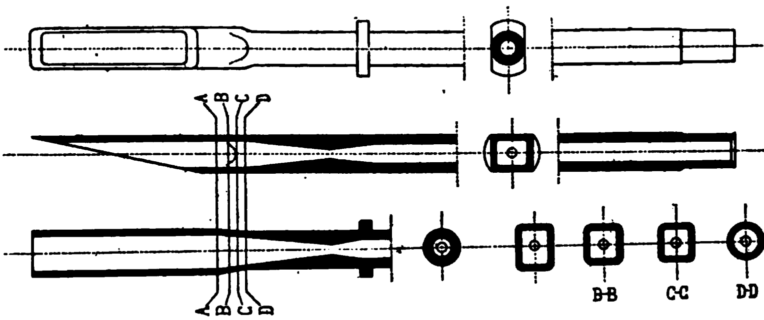


FIG. 189.—One Nozzle of 2000 Horse-power Turbine.

sistent with the dimensions shown in Fig. 182, where the thickness at the centre is 5 centimetres.

Nozzles.—It has been found that corrosion on the inner walls of the nozzles tends to decrease the speed of flow of the steam. The nozzles of the Riedler-Stumpf turbine are made of nickel steel with a high percentage of nickel, and it is claimed that this source of deterioration is thus obviated.

A rectangular cross section of nozzle is employed. The construction of a single nozzle of the Moabit 2000 horse-power turbine is indicated in Fig. 189, and in the four sections at A, B, C, and D there is depicted the gradual change from the circular section of the nozzle at the throat to the rectangular section at the discharge end.

In Figs. 190 A and B are shown respectively a drawing and a photograph of the ring for holding the 80 nozzles which are

employed in this design. The precise method of arrangement of the nozzles in the casing is shown in Fig. 191. The rectangular form of the nozzle permits of discharging a nearly continuous belt of steam and a full utilisation of the buckets. In some of the smaller sizes of Riedler-Stumpf turbine it is not necessary to have a complete ring of nozzles over the periphery. In such cases, instead of distributing the nozzles at equal distances around the periphery, they are placed in a single group at one section of the periphery.

The impossibility of obtaining very low speeds by the use of a single wheel acted upon but once by the jet of steam led to

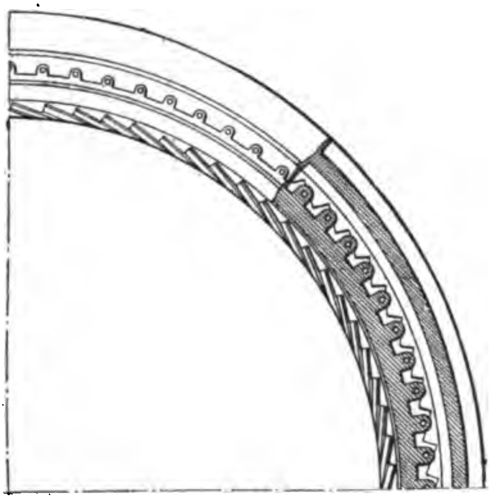


FIG. 190A.—Riedler-Stumpf 2000 Horse-power, 3000 R.p.m.
Ring for Holding Nozzles.
(*From the Designers.*)

suggested modifications of the simple form of Reidler-Stumpf turbine from that embodied in the 2000 horse-power, 3000 revolutions per minute, Moabit machine.

The first of these suggested modifications consisted in the introduction of two successive impacts of the steam upon a single wheel by means of stationary reversing nozzles. This plan appears to have been proposed by Pilbrow in 1843, and has been very clearly described by Lilienthal in 1890. The Riedler-Stumpf reversing nozzle, Fig. 192, resembles the arrangement described by Lilienthal which is illustrated in Fig. 193, and may be described as follows:—

Lilienthal showed a simple figure to explain a way of intro-

ducing the steam a second time into the revolving buckets. This figure has been reproduced in Fig. 193, and it can be seen that the

FIG. 190B.—Ring of Nozzles.

expanding nozzle delivers steam into one bucket *a* of the revolving wheel, and this discharges into the stationary reversing guide

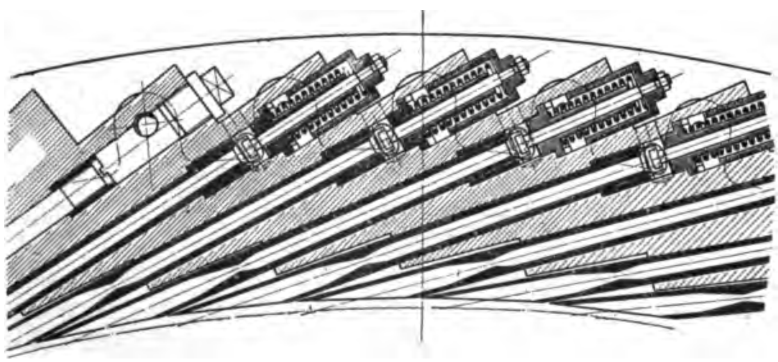


FIG. 191.—Riedler-Stumpf Nozzles in Casing.

marked *c*, which in turn delivers into the next bucket *b*. The helical shape of the reversing guide is necessary in order to take the steam to the adjacent bucket. The figure is merely diagram-

matical, and shows no clearance between the fixed reversing guide

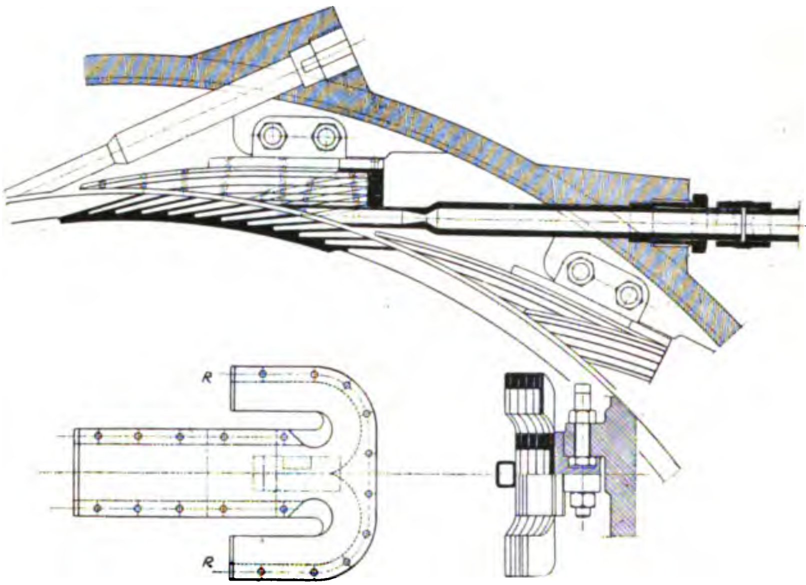


FIG. 192.—Reversing Nozzle.

c and revolving buckets *a* and *b*. Such clearance would, of course, be necessary in a practical machine. From the above preliminary

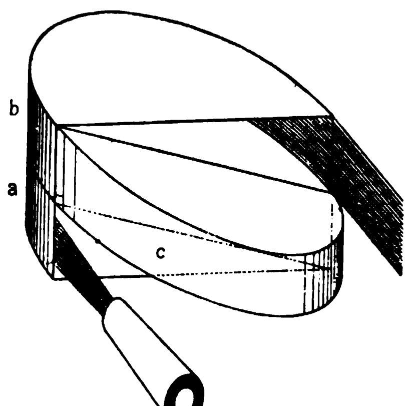


FIG. 193.—Lilienthal Reversing Nozzle.
(*Musil.*)

description of Lilienthal's proposal it will perhaps be easier to follow the course of the steam in Riedler's design as shown in

Fig. 192. The expanding nozzle delivers a jet of steam at the middle of the double row of overlapping buckets in Fig. 183. The knife edges between these two rows are visible in the upper buckets of Fig. 183, also in the section A B of Fig. 182.

The discharge from these two buckets is received at R R of the reversing guide shown in Fig. 192, and the two parts of this guide unite and redeliver the steam to adjacent buckets.

Riedler - Stumpf designs with pressure stages. — It has also been proposed to obtain Riedler-Stumpf turbines for low

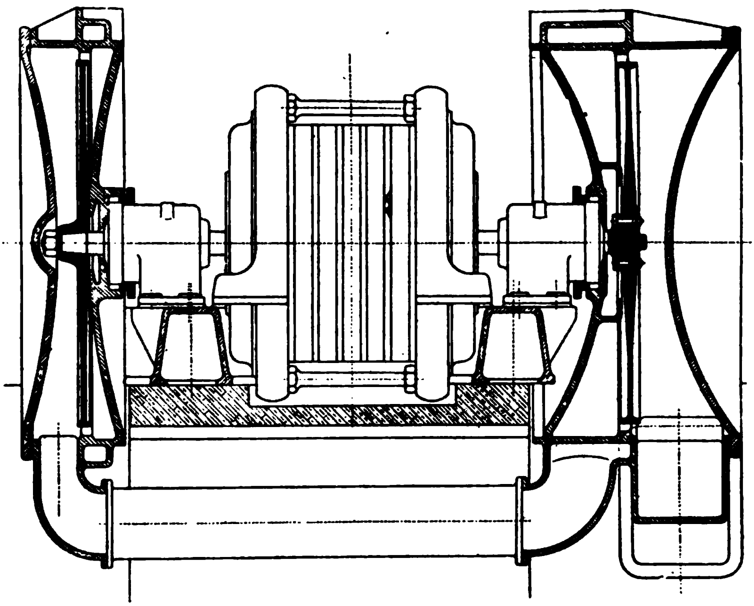


FIG. 194.—5000 K.W. 750 R.p.m. Design.

speed by means of two and even four pressure stages. Thus in Fig. 194 is sketched a design for a 5000 K.W. machine for a speed of 750 revolutions per minute. This has two pressure stages, and the single wheel of each stage is twice acted upon by the steam.

Fig. 195 is a sketch of a 500 K.W. set for the very low speed of 500 revolutions per minute. It has four pressure stages, and the buckets of each wheel are twice acted upon by the steam. It is very certain that this design would require a relatively high steam consumption, but in the interests of obtaining a thoroughly satisfactory design for the direct driving of a continuous current generator a reduction of the speed is justifiable, even at a con-

siderable sacrifice in economy. In the case of this design, in which, from the overall dimensions given, it is evident that the wheels have a diameter of about 2 metres, the peripheral speed has the very low value of 52 metres per second. It is not clear why it would not be preferable to at least double the wheel diameter, and correspondingly reduce the number of stages. The use of so low a peripheral speed at once sacrifices one of the most attractive amongst the underlying principles of the Riedler-Stumpf type.

Vertical-Shaft Riedler-Stumpf Turbines.—A design for a

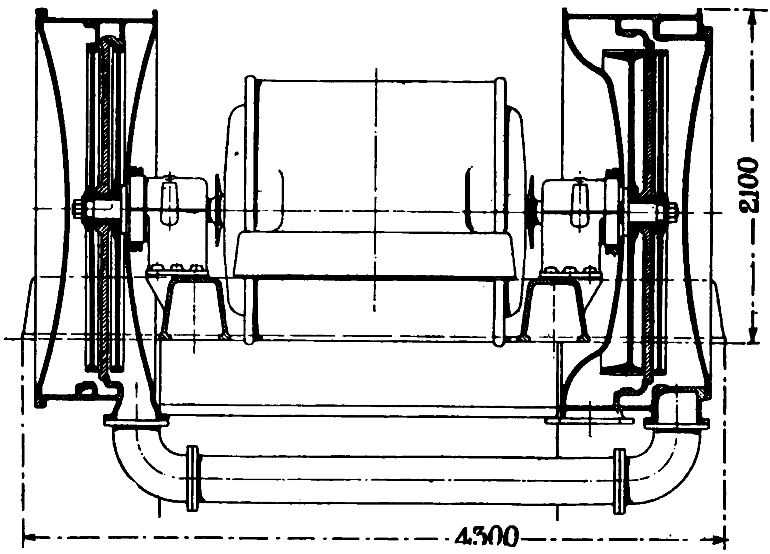


FIG. 195.—Riedler-Stumpf 500 K.W. Turbo-dynamo, 500 R.p.m.

2000 K.W. 750 revolutions per minute set with a vertical shaft is shown in Fig. 196. This design is worked out with two pressure stages and two speed steps per pressure stage. In Fig. 197 we have an illustration of a 500 kilowatt 750 revolution per minute vertical design with four pressure stages and two speed steps per pressure stage. The peripheral speed in this design is 118 metres per second, the diameter of the wheels being about 3 metres.

Riedler's general conclusion, however, appears to be that while reduction of speed by means of many pressure stages is consistent with high economy, it is undesirable to employ more than two speed steps per pressure stage, as this entails great friction losses between the steam and the buckets and reversing nozzles.

While the Riedler-Stumpf turbine in its simplest form with a single wheel differed from the de Laval design chiefly in the far

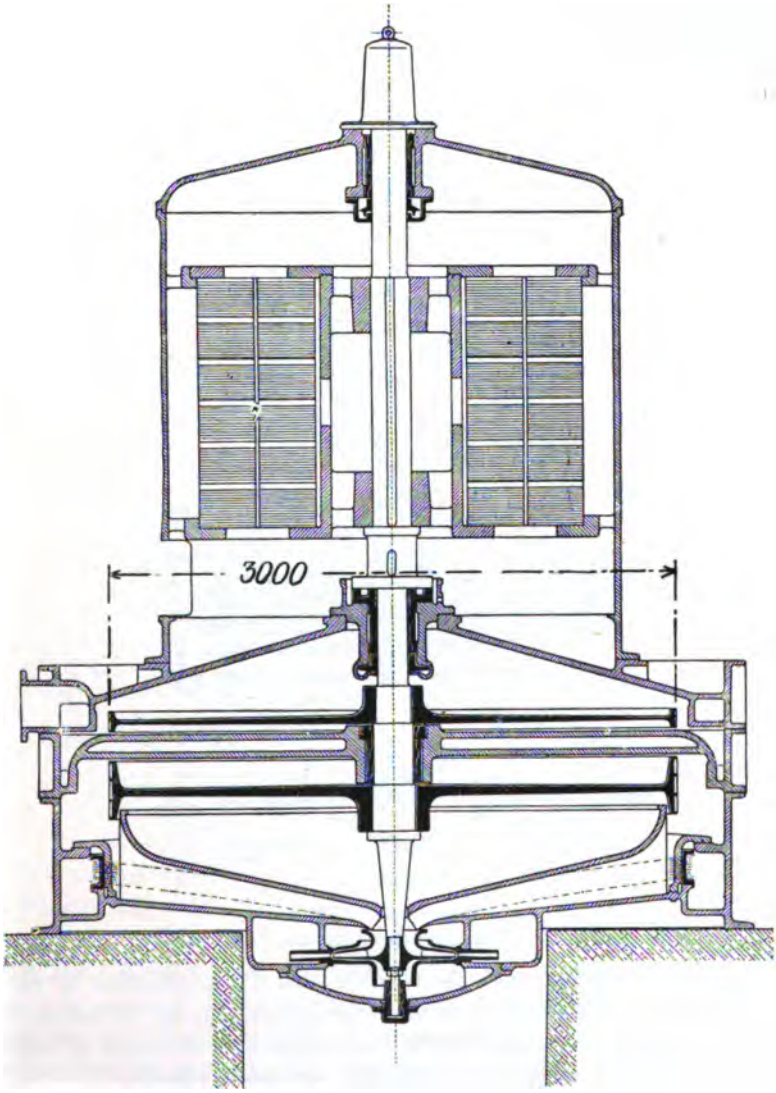


FIG. 196.—2000 K.W., 750 R.p.m., Vertical Design.

greater wheel diameter, and the consequent avoidance of reduction gearing, the types with both pressure and speed stages are closely on the lines of the Curtis turbine. The Riedler-Stumpf turbines

were for a time built by the Allgemeine Elektricitaets-Gesellschaft of Berlin.

The Riedler-Stumpf type has now more or less merged its identity in the A. E. G. type described in the following chapter. It seems to the writers that while the main ideas of the original type with a single wheel were most attractive, these were carried

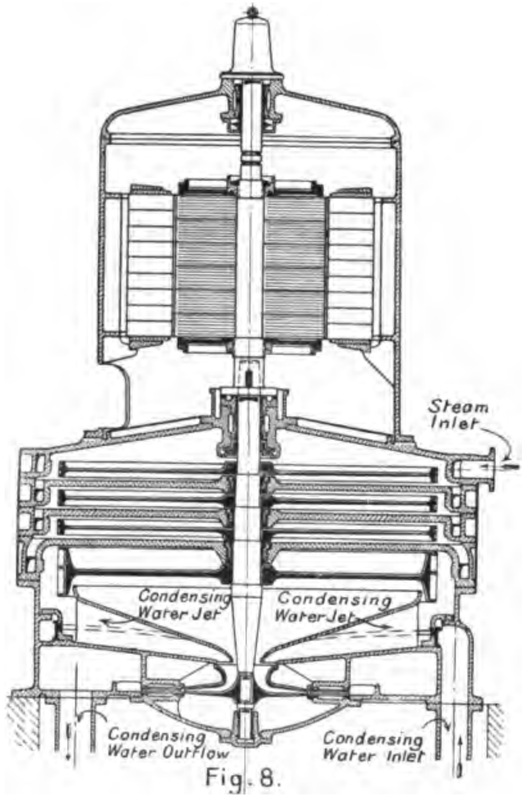


FIG. 197.—500 K.W. 750 R.p.m.
(From *The Engineer.*)

to an extreme which was inconsistent with the production of safe constructions. As development in the production of materials of great strength proceeds, there will doubtless be a reversion towards large diameters, accompanied by high peripheral speeds.

Grauert's contribution to the discussion of Riedler's paper on Steam Turbines[1] is published in the *Marine Rundschau* for January 1904, and contains data of a small Reidler-Stumpf turbo-

[1] "Ueber Dampfturbinen," by Herr Prof. Dr. ing. Riedler, *Jahrbuch der Schiffbautechnischen Gesellschaft*, vol. v. (1904), p. 249.

generating set. The set has a rated full-load capacity of 65 kilowatts at 110 volts, and four such sets constitute a plant of a capacity suitable for lighting purposes on certain vessels of the German navy. The overall dimensions of one of these 65 kilowatt sets are set forth in Fig. 198. The conditions of operation as regards admission pressure, vacuum, and superheat are not given, but it is stated that the full-load steam consumption was 17·1 kilograms per kilowatt-hour. The weight is 3000 kilograms. The speed is not given. It is stated that the price tendered was

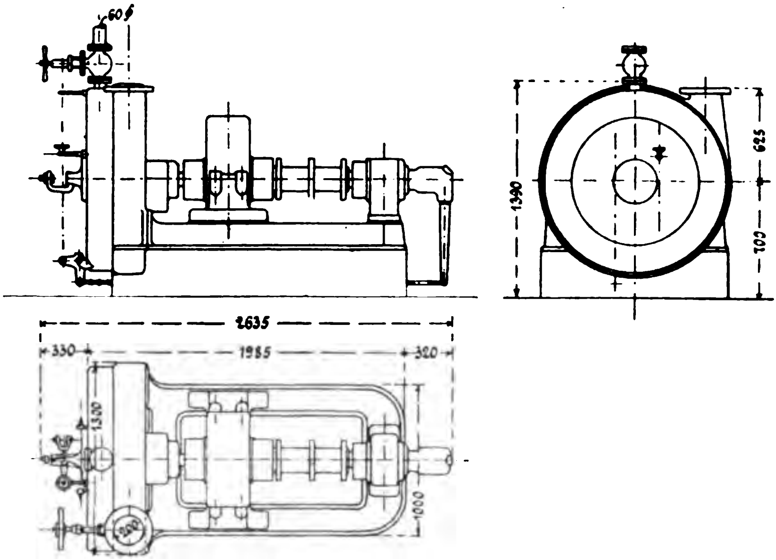


FIG. 198.—65 K.W., 110 Volt, Riedler-Stumpf Turbo-dynamo. *Dimensions in Millimetres.*

80,000 marks for four of these sets, or £1000 per set. This is £15·4 per kilowatt.

A still smaller Riedler-Stumpf steam turbine set has been described. This is the 20 horse-power set illustrated in Fig. 199. It runs at 3500 revolutions per minute, and the wheel diameter is 810 millimetres. The peripheral speed is thus only 148 metres per second. The machine runs non-condensing, and the steam is completely expanded to atmospheric pressure in the nozzles. The admission pressure is not given, but it is stated that in designs with but a single impact of the steam the full-load steam consumption was 26 kilograms per kilowatt-hour, and that in designs with two successive impacts by means of stationary

reversing nozzles (as in the design illustrated in Fig. 199) the steam consumption was decreased to 17 kilograms per kilowatt-hour for the same speed and output.

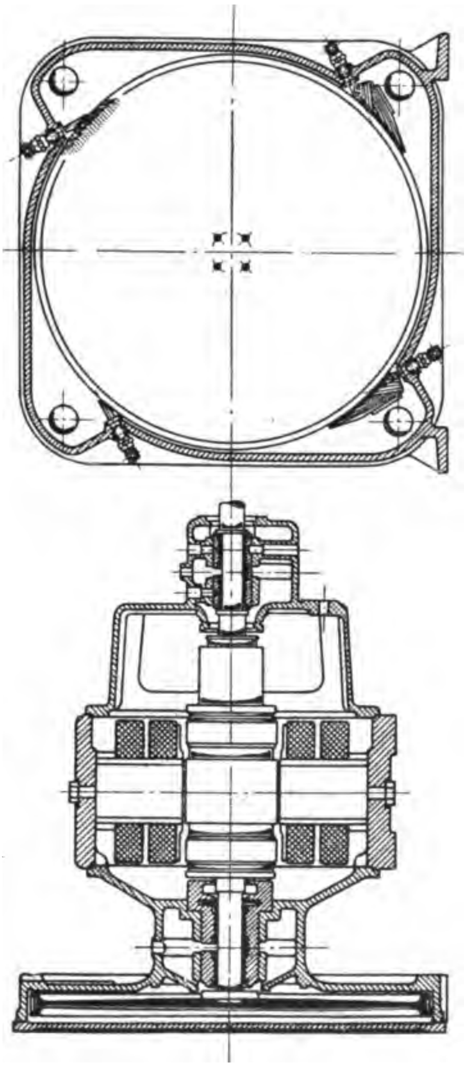


FIG. 199.

Steam Consumption.—The published results as regards the steam consumption of the Riedler-Stumpf turbine are brought together in Table LXXVI.

TABLE LXXVI.—TEST RESULTS ON RIEDLER-STUMPF TURBO-GENERATING SET, RATED OUTPUT OF 1475 K.W., AND DIRECT-COUPLED TO D. C. DYNAMO.

Reference Numbers.	Percentage of Rated Full Load.	Rated Load in Kilowatts.	Speed in Revolutions per Minute.	Pressure at Inlet Valve (absolute) in Kgs. per sq. cm.	Pressure at Nozzles (absolute) in Kgs. per sq. cm.	Degrees Cent. of Superheat at admission.	Percentage Vacuum.	Steam Consumption in Kgs. per K.W. Hour Output from Dynamo.	Date of Test.	Place of Test.	Manufacturer of Turbine.	Source of Data.
I.	37	554	3000	14·75	8·14	103	89	9·9	July 1903.	Berlin.	A. E. G.	Riedler (paper entitled "Ueber Dampfturbinen," read before the Schiffbautechnischen Gesellschaft, Berlin. *Proceedings*, vol. v. (1904), p. 249).
	57	850	,,	,,	9·27	124	92	9·4				
	57	850	,,	,,	9·38	113	92	9·2				
	92	1365	,,	,,	10·30	118	85	8·9				
II.	91	1345	3800	14·75			85	7·5				

CHAPTER IX

THE A.E.G. TURBINE

THE Allgemeine Elektricitäts-Gesellschaft of Berlin first entered the turbine field with designs of the Riedler-Stumpf type. Within the last two years, however, the rights for the Curtis turbine patents in several countries have come into their hands, and the situation has led to the development of a distinctive A.E.G. type.

Owing to these circumstances there has been a long developmental period during which numerous varied types have been built.

The 2000 Horse-power Riedler-Stumpf set at the Moabit Central Station, which was built by the Allgemeine Elektricitäts-Gesellschaft, has already been described in Chapter VIII.

Numerous other earlier types have been described in an article on p. 1205 of the *Zeitschrift des Vereines Deutscher Ingenieure* for August 13th, 1904, entitled "Die Dampfturbinen der Allgemeine Electricitäts-Gesellschaft, Berlin." The article is by Mr O. Lasche, the director of the turbine department of the Allgemeine Elektricitäts-Gesellschaft. We do not propose to dwell upon these earlier types, in some of which two cylinders were employed, but shall confine our attention chiefly to some examples of the latest designs, photographs of which have been placed at our disposal for this purpose by the courtesy of Mr Lasche. In these latest designs a single overhung cylinder is employed.

General Construction.—The design arrived at has been adopted from a consideration of the requirements of the dynamo no less than those of the turbine. The dynamo is secured to a base plate between two main bearings, and the turbine is supported upon an extension of the base plate. A small additional

bearing is provided in the end casing of the turbine merely to guide the end of the shaft and to take up the weight of the regulator. All stresses are transmitted by the two main bearings to the base plate. It is claimed that only the lightest of foundations are required.

The Turbine.—The turbine has two pressure stages, and each pressure stage has two speed stages. The casing is divided by an intermediate partition into two compartments, in each of which a wheel revolves. Each wheel is designed for two speed stages, and thus carries two rows of vanes.

Turbine Wheels.—The wheels are built of a high quality of steel and have a large factor of safety. The peripheral speeds are fairly moderate. The two wheels are located side by side on the shaft in the single casing, and are separated only by the intermediate partition. The vanes are of tough material and are mounted in the rims of the wheels.

Casing.—The casing is constructed of cast-iron. It is subjected to a hydraulic test at high pressure, although in practice it is seldom exposed to an absolute pressure of more than 2 kilograms per square centimetre, since the steam is expanded down to almost atmospheric pressure before actually entering the first-stage compartment. A safety-valve is provided as protection against any chance increase in pressure occurring in service. The casing is jacketed with non-conducting material, and the outer covering consists of polished sheet metal together with the end castings.

Method of Operation.—The steam first passes through a sieve of fine mesh, and then enters the steam chamber after leaving the admission valve. It then enters the nozzles of the first stage. In these nozzles, which are secured in the casing, a large part of the energy of the steam is transformed into kinetic energy, and after emerging from the nozzle at high speed and low pressure, it impinges on the first row of vanes of the first wheel. It is then guided by reversing vanes against the second row of vanes of the same wheel. The steam then enters a second set of diverging nozzles located in the partition between the two pressure stages and is expanded again in these to a high speed, and after going through a similar process in the second stage, passes off to the condenser.

When turbines are required to work either condensing or non-condensing, a valve is supplied between the turbine and the condenser. In order that the turbine when running non-

condensing may carry nearly its full load, and as economically as possible, only a part of the full supply of steam is carried to the second stage; the remainder is exhausted into the atmosphere immediately after having completed its work in the first stage. The discharge from the first stage is generally ultimately conveyed to the atmosphere by the same pipe which discharges from the second stage.

Bearings.—Oil is carried under pressure to the bearings, a

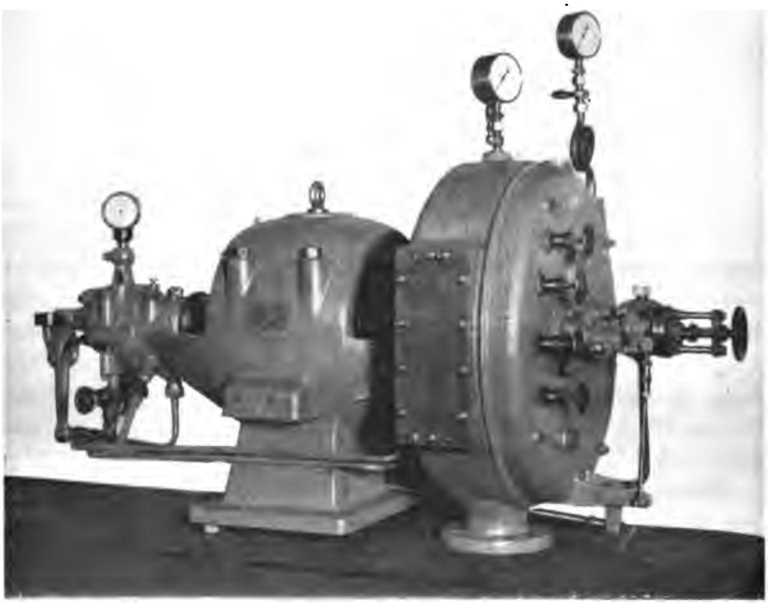


FIG. 200.—10 K.W. A.E.G. Set.

rotary pump, driven by the turbine itself, being provided for the purpose. The bearings are cooled by water circulation.

Shaft.—The shaft is of nickel steel or of Siemens-Martin steel, both these materials having been found equally satisfactory as regards their behaviour at the bearing surfaces.

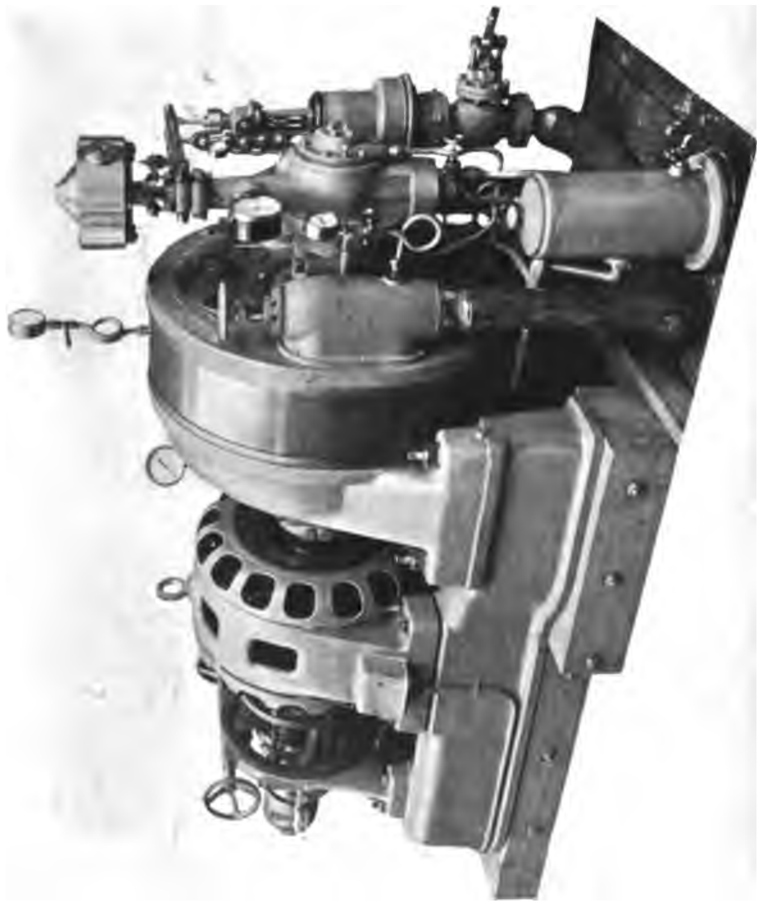
The photographs in Figs. 200 and 201 illustrate sets for 10 and 20 kilowatt. This latter set was designed for a marine installation. Some of the leading data of these two small sets is given in Table LXXVII.

Fig 201.—A.E.G. 20 K.W. Continuous Current Marine Type Turbo-Generator.

Table LXXVII.

Rated output	10 K.W.	20 K.W.
Speed in R.p.m.	4000	3600
Voltage	115	115
Absolute steam pressure in kgs. per sq. cm. . . .	9·65	11·5
Superheat in degrees Cent.	57°	63°
Vacuum	90·8%	85%
Approximate steam consumption at rated full load in kgs. per kilowatt-hour	19·2	15·8
Complete weight of set	630 kg.	1220 kg.
Peripheral speed of turbine wheel in metres per second	105	120
Peripheral speed of commutator in metres per second .	24	26
Material of the brushes	carbon	carbon

Description of the Regulator.—The regulator is driven from the main shaft by means of worm gearing. The Allgemeine Elektricitäts-Gesellschaft does not wish to publish details of this regulator at present, further than to state that it acts indirectly



IG. 292.—A.E.G. [illegible] K. W. Continuous Current Turbo-Generator (turbine end).

by controlling the pressure of the oil behind a piston in a small cylinder. This piston acts on the throttle valve. Their former method of regulation by means of opening and closing the communication with the several nozzles by the position of a steel band (see Stodola, *Die Dampfturbine*, pp. 252 and 253, Figs. 224, 225, and 226) has been abandoned, for constructional reasons.

The new method of regulation is stated to be exceedingly sensitive. The regulator is located immediately behind the

TABLE LXXVIII.

	I.	II.	III.	IV.
	Rated full load.	¾ load.	½ load.	½ load.
Speed in R.p.m.	3000	3000	3000	3050
Absolute admission pressure in Kgs. per sq. cm.	13	13	13	13
Temperature of steam at admission in degs. Cent.	300°	300°	300°	285°
Superheat in degs. Cent.	109	109	109	94
Absolute steam pressure at admission to Stage II. in Kgs. per sq. cm.	0·974	0·795	0·605	0·51
Temperature of steam at admission to Stage II. in degs. Cent.	124°	122°	118°	115°
Vacuum in low-pressure chamber	90·8%	90·8%	90·8%	95·2%
Oil pressure in Bearing I.—Kgs. per sq. cm.	2·3	2·3	2·3	2·1
Oil pressure in Bearing II.	2·2	2·2	2·2	2·0
Oil pressure in Bearing III.	2·0	2·0	2·0	...
Temperature of Bearing I.—degs. Cent.	30°	30°	30°	27°
Temperature of Bearing II.—degs. Cent.	55°	56°	56°	57°
Temp. of Bearing III.—degs. Cent.	53°	50°	50°	52°
Pressure in Stuffing Box — Kgs. per sq. cm.	2·2	2·2	2·2	4·0
Steam consumption in kilograms per hour	7500	6115	4660	3955
Output in kilowatts	1000	750	500	451

throttle valve. On suddenly throwing off rated full load the increase in speed does not exceed 5 per cent. An alteration of 25

per cent. in the load is accompanied by a speed variation of about 2 per cent. The momentum of the revolving parts prevents over-regulation.

In addition to this regulation a safety-governor is provided. This is located direct on the turbine shaft and controls the main valve, which is arranged as a quick-acting cut-off valve, which can be actuated by hand as well as by the safety-governor. This safety-governor is brought into action by any increase of speed beyond 15 per cent. above the normal rated speed.

A 100-kilowatt set is illustrated in Figs. 202 and 203, and a 1000-kilowatt three-phase set in Fig. 204.

Tests on this 1000-kilowatt set have given the results set forth in Tables LXXVIII. and LXXIX.

TABLE LXXIX.

	Steam Consumption in Kgs. per Kilowatt-hour.	Vacuum.	Superheat in Degs. Cent.
Rated full load	7·50	90·8%	109
¾ load	8·15	90·8%	109
½ load	9·32	90·8%	109
½ load	8·78	95·2%	94

Certain further details of this 1000 K.W. set and of a 150 K.W. set are set forth in Table LXXX.

TABLE LXXX.

Rated output	150 K.W.	1000 K.W.
Speed in R.p.m.	3000	3000
Type of dynamo	Cont. curr.	3-phase
Voltage	550 volts	3,000 volts
Periodicity	...	50 cycles
Absolute steam pressure in Kgs. per sq. cm.	10·5	13
Superheat in degs. Cent.	123	109
Vacuum in per cent.	95	90·8
Approximate steam consumption at rated load, in Kgs. per kilowatt-hour	9·17	7·50
Complete weight of set	8,500 Kg.	40,000 Kg.
Peripheral speed of commutator in metres per second	40	...
Material of the brushes	metal	...

The Allgemeine Elektricitäts-Gesellschaft builds polyphase turbo-generating sets in capacities of from 100 kilowatts to 6000

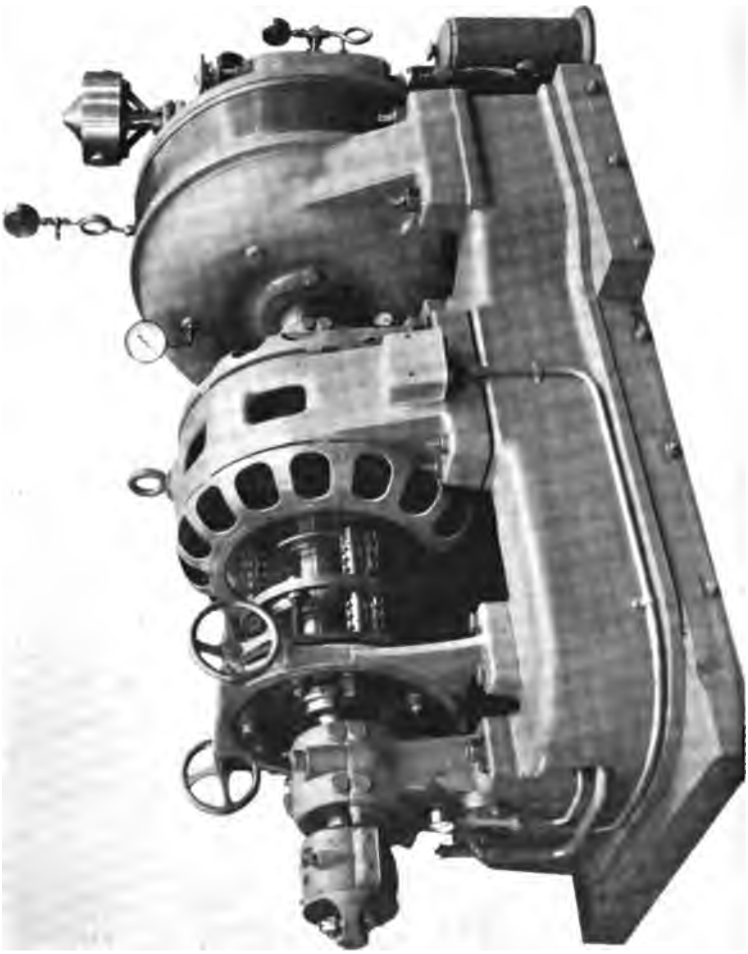


Fig. 203.—A.E G. 100 K.W. Continuous Current Turbo-Generator (generator end).

kilowatts. The speeds for a periodicity of 50 cycles per second are as follows:—

TABLE LXXXI.

Rated Output in K.W.	Speed in R.p.m.	No. of Poles.
100 to 1000	3000	2
1500 to 3000	1500	4
4000 to 6000	1000	6

Continuous-current turbo-generating sets are built in capacities ranging from 50 kilowatts up to 750 kilowatts. The speeds are as follows:—

TABLE LXXXII.

Rated Output in K.W.	Speed in R.p.m.
50 to 300	3000
500	2000
750	1500

All these machines have metal brushes.

In addition to the above line of machines, a line employing carbon brushes is built in capacities of from 2 kilowatts to 20 kilowatts. These are made in the sizes shown in Table LXXXIII.

TABLE LXXXIII.

Rated Output in Kilowatts.	Volts.	Speed in R.p.m.
2	115	5000
5	65 and 115	4500
10	115	4000
15	65 and 115	4000
20	115	3600

In polyphase sets for operation in parallel, the regulation is provided with a spring adjustment controlled by a hand wheel, which permits of bringing the speed of the unloaded machine down to the speed of the loaded machine with which it is to be synchronised.

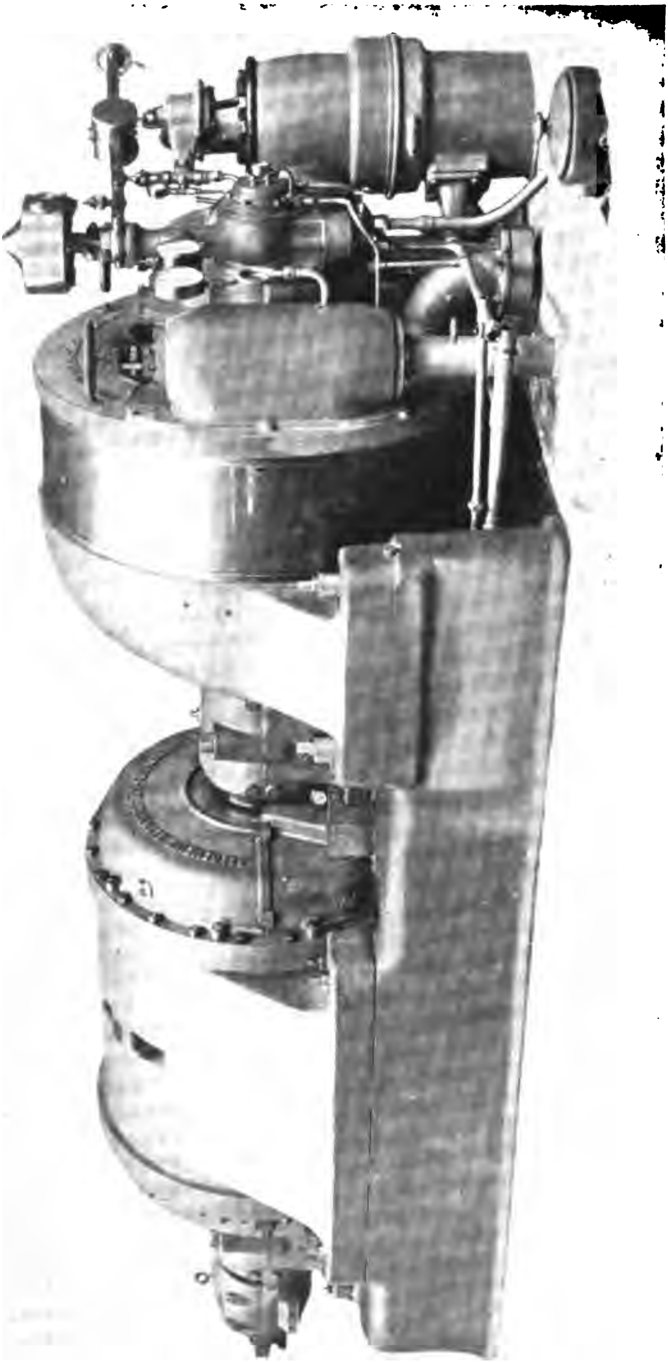


FIG. 204.—A.E.G. 1000 K.W. 3-Phase Turbo-Generating Set.

Tests on a 470-kilowatt A.E.G. three-phase, 550 volt, 3000 revolutions per minute, 50 cycle, turbo-generating set.

Particulars of some tests made on this set in February 1905 at the works of the Allgemeine Elektricitäts-Gesellschaft have been published in an article[1] on p. 633 of *Glückauf* for May 20th, 1905.

The rated full load for this set is 470 kilowatts and a power factor of 0·8.

In this set the dynamo is located between two bearings, outside of each of which is an overhung turbine casing.[2] The overall length of the set is 5025 millimetres, the width 2200 millimetres, and the height above the engine-room floor 2100 millimetres. The set thus occupies a floor space of 11·0 square metres, or $\frac{500}{11 \cdot 0} = 45 \cdot 5$ kilowatts per square metre of floor space.

The turbine wheels, which are of nickel steel, have a diameter of 1700 millimetres, the peripheral speed thus being 267 metres per second. The steam is admitted to the first stage through 28 nozzles, and then passes to the second stage, entering through 68 nozzles. It then flows off to the condenser. The turbine can also carry its full rated load continuously when working non-condensing.

Steam consumption curves derived from tests made on this turbine are given in Fig. 205.

In Table LXXXIV. are tabulated the no-load test results on a 470-kilowatt A.E.G. turbine. Full-load steam consumption per hour = 5000 kilograms. No-load steam consumption per hour = 1046 kilograms. No-load steam consumption is therefore approximately one-fifth of the total steam consumption at full rated load.

TABLE LXXXIV.[3]—NO-LOAD TESTS ON A 470 K.W. A.E.G. TURBINE.

R.p.m.	Absolute Pressure in Kgs. per sq. cm.	Exhaust pressure in Kgs. per sq. cm.	Superheat.	Steam Consumption at No-Load in Kgs. per hour.
3015	10·0	0·10	0	1046

[1] "Untersuchung einer 500 K.W. Turbodynamo für die Zeche Preussen I.," von Oberingenieur F. Schultze, Dortmund.

[2] This type represents an intermediate stage in the development of the present A.E.G. turbine. In the present type the turbine is located entirely at one end.

[3] From *Glückauf*, p. 635, May 20th, 1905.

The test results shown in Table LXXXV. (reference numbers III., IV., VI., and IX.) have been derived from curves given in the article by O. Lasche, entitled "Die Dampfturbinen der A.E.G., Berlin" (*Zeitschr. Vereines Deutsch. Ing.*, p. 1207, August 13th, 1904). The pressure under which the above tests were conducted was 12 kilograms gauge pressure, or 13 kilograms absolute pressure. The vacuum is not stated in the article, but the manufacturers have kindly furnished us with particulars in which they state that a

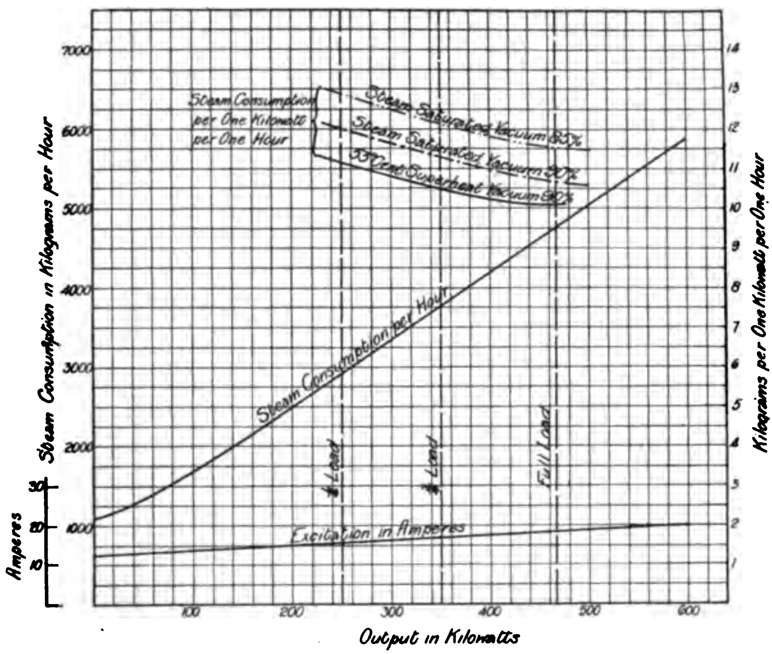


FIG. 205.—Steam Consumption : A.E.G. 470 K.W. Set.

95 per cent. vacuum was employed in these tests, but that they can now get the same steam economy when employing a vacuum of from 90 to 91 per cent. It has therefore been thought advisable by the authors, in the case of these tests, to state the corresponding vacuum for the tests as being 92 per cent.—an intermediate value. The manufacturers further state that the temperature of the steam was 300° C., which for 13 kilograms absolute pressure gives a superheat of about 109° C.

The test results set forth in Table LXXXV. have been corrected so as to correspond to the standard conditions of reference, namely, of 13 kilograms absolute pressure, a vacuum of 86·6 per cent. and

TABLE LXXXV.—SUMMARY OF TEST RESULTS

Reference Number.	Rated Output reduced to Terms of K.W. from Dynamo at Rated Load.	Speed in Revolutions per Minute.	Results for 20 per Cent. of Rated Load. Admission Pressure (absolute), Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Degrees Cent. Superheat at Admission.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo.	Results for 40 per Cent. of Rated Load. Admission Pressure (absolute), Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Degrees Cent. Superheat at Admission.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo.	Results for 60 per Cent. of Rated Load. Admission Pressure (absolute), Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Degrees Cent. Superheat at Admission.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo.	Results for 80 per Cent. of Rated Load. Admission Pressure (absolute), Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Degrees Cent. Superheat at Admission.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo.
I.	10	4000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
II.	20	3600	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
III.	75	..	13·0	0·08	109	17·8	13·0	0·08	109	15·8	13·0	0·08	109	14·1	13·0	0·08	109	13·0
IV.	100	..	..	..	..	..	13·0	0·08	109	11·6	13·0	0·08	109	10·5	13·0	0·08	109	10
V.	150	3000	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
VI.	350	..	..	..	..	..	..	..	..	..	..	..	..	..	13·0	0·08	109	8·3
VII.	470	3000	11·0	0·10	53	12·7	11·0	0·10	53	11·6	11·0	0·10	53	10·9	11·0	0·10	53	10·4
	470	3000	11·0	0·10	0	14·0	11·0	0·10	0	12·6	11·0	0·10	0	11·75	11·0	0·10	0	11·2
	470	3000	11·0	0·15	0	15·2	11·0	0·15	0	13·7	11·0	0·15	0	12·6	11·0	0·15	0	12·0
VIII.	1000	3000	..	..	..	..	..	..	..	..	13·0	0·092	109	8·8	13·0	0·092	109	8·0
IX.	1000	..	13·0	0·08	109	12·2	13·0	0·08	109	8·45	13·0	0·08	109	7·8	13·0	0·08	109	7·5

50° of superheat. The curves used in the case of the de Laval turbine, for estimating the variation in steam consumption for a

ON STEAM CONSUMPTION OF A.E.G. TURBINES.

Reference Number.	Results for 100 per cent. of Rated Load: Admission Pressure (absolute), Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Degrees Cent. Superheat at Admission.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo.	Results for 120 per cent. of Rated Load: Admission Pressure (absolute), Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Degrees Cent. Superheat at Admission.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo.	Date of Test.	Place of Test.	Manufacturer of Turbine.	Source of Data.
I.	9·65	0·092	57	19·2	..	..	..	..	..	Berlin	A.E.G.	Supplied to Authors by Manufacturers.
II.	11·5	0·15	63	15·8	..	..	..	..	..	"	A.E.G.	Supplied to Authors by Manufacturers.
III.	13·0	0·08	109	12·5	13·0	0·08	109	12·1	1904	"	A.E.G.	*Zeit. Vereines Deutsche Ingenieure*, August 13, 1904, p. 1207.
IV.	18·0	0·08	109	9·8	18·0	0·08	109	10·0	1904	"	A.E.G.	*Zeit. Vereines Deutsche Ingenieure*, August 13, 1904, p. 1207.
V.	10·5	0·05	123	9·17	..	..	..	..	..	"	A.E.G.	Supplied to Authors by Manufacturers.
VI.	13·0	0·08	109	8·4	13·0	0·08	109	8·2	1904	"	A.E.G.	*Zeit. Vereines Deutsche Ingenieure*, August 13, 1904, p. 1207.
VII.	11·0	0·10	53	10·1	..	..	..	..	1905	"	A.E.G.	*Glückauf*, May 20, 1905, p. 635.
	11·0	0·10	0	10·7	..	..	..	..	1905	"	A.E.G.	*Glückauf*, May 20, 1905, p. 635.
	11·0	0·15	0	11·5	..	..	..	..	1905	"	A.E.G.	*Glückauf*, May 20, 1905, p. 635.
VIII.	18·0	0·092	109	7·5	..	..	..	..	1905	"	A.E.G.	Supplied to Authors by Manufacturers.
IX.	13·0	0·08	109	7·5	13·0	0·08	109	7·8	1904	"	A.E.G.	*Zeit. Vereines Deutsche Ingenieure*, August 13, 1904, p. 1207.

variation in pressure, vacuum, and superheat, were employed in obtaining the values corresponding to these standard conditions.

The derived results are set forth in Table LXXXVI. Since in the A.E.G. turbines the expansion is completed in the nozzles, it is believed that the correction factors for variations in pressure, superheat, and vacuum should approximate to those derived from

TABLE LXXXVI.—SHOWING THE INFERRED STEAM CONSUMPTION, WITH A CONSTANT ABSOLUTE STEAM PRESSURE OF 13 KGS., A VACUUM OF 86·6 PER CENT., AND 50° C. OF SUPERHEAT FOR THE A.E.G. TURBINE, AS DERIVED FROM TEST RESULTS ON TABLE LXXXV.

Reference Number.	Rated Output reduced to Terms of Kilowatts from Dynamo at Rated Load.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo. Results for 20% of Rated Load.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo. Results for 40% of Rated Load.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo. Results for 60% of Rated Load.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo. Results for 80% of Rated Load.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo. Results for 100% of Rated Load.	Kgs. Steam Consumption per K.W. Hour Output from Dynamo. Results for 120% of Rated Load.
I.	10	...	...	...	...	19·6	...
II.	20	...	...	...	...	15·4	...
III.	75	20·0	17·8	15·8	14·6	14·0	13·6
IV.	100	...	13·0	11·8	11·2	11·0	11·2
V.	150	...	...	...	...	10·5	...
VI.	350	...	...	...	9·5	9·4	9·2
VII.	470	13·0	11·9	11·2	10·7	10·4	...
VII.	470	13·3	12·0	11·2	10·7	10·3	...
VII.	470	13·4	12·2	11·2	10·7	10·2	...
VIII.	1000	...	...	10·2	9·1	8·5	...
IX.	1000	13·7	9·45	8·75	8·4	8·4	8·75

our analysis of the results on de Laval turbines. Thus, in examining the tests on the 470-kilowatt set as given in Table LXXXV., we find that 53° Cent. of superheat at nearly constant admission pressure and vacuum reduces the steam consumption by 5·6 per cent. as against 7·4 per cent., corresponding to the curve in Fig. 31 for the de Laval turbine. The tests on the 470-kilowatt set at constant admission pressure and temperature, but with a 5 per cent.

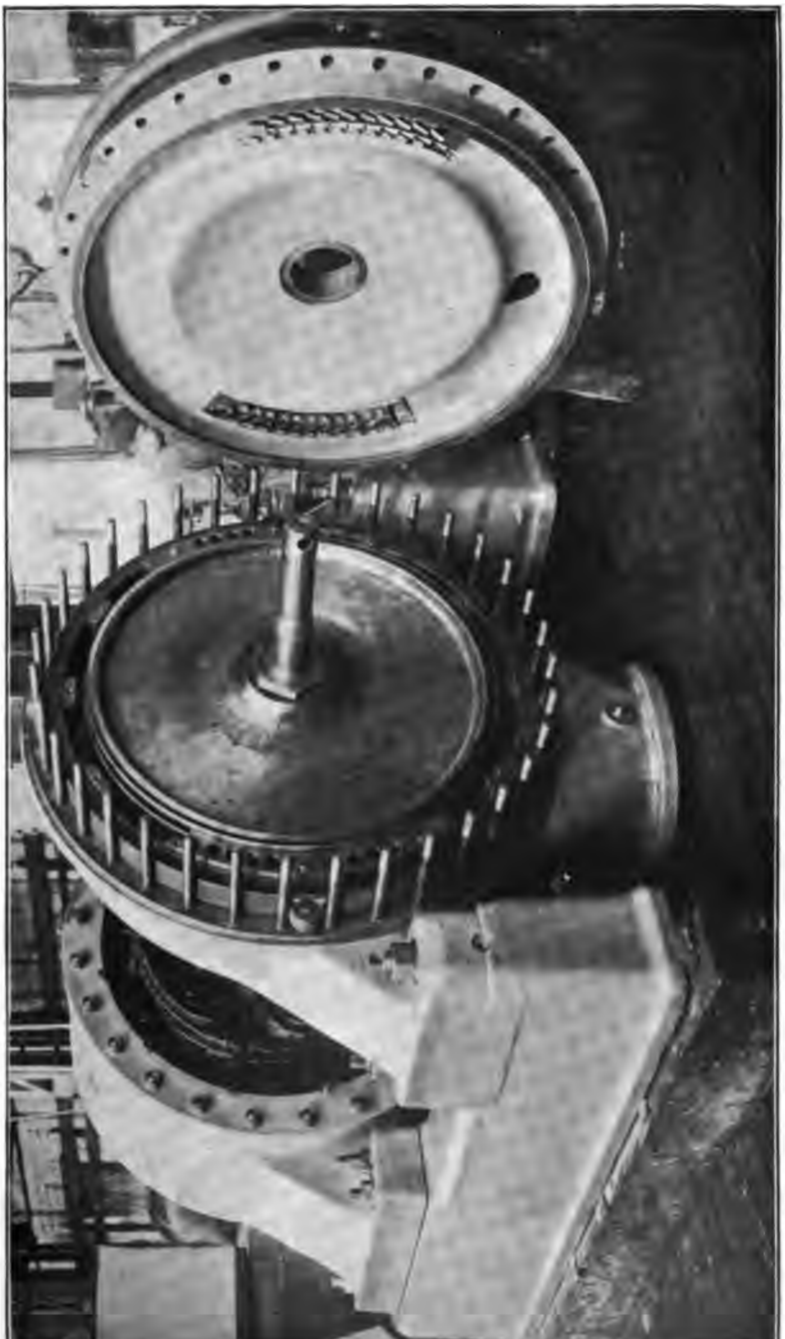


Fig. 206.—A.E.G. Turbine with Nozzle Cover removed. 300 K.W.

improvement in vacuum, show a decreased steam consumption of 7 per cent. as against 6·25 per cent., corresponding to the curve in Fig. 23 for the de Laval turbine.

The Allgemeine Elektricitäts-Gesellschaft also manufacture condensers for steam turbine installations, one type of which is indicated in Figs. 196 and 197 in the base of their vertical type of Riedler-Stumpf turbine.

Admission Nozzles.—Fig. 206 shows a photograph of the interior of a turbine set.

CHAPTER X

THE HAMILTON-HOLZWARTH TURBINE

THE Hamilton-Holzwarth Steam Turbine resembles the Parsons in that the steam flows through the turbine in a continuous belt. But whereas the steam in the Parsons type expands both in the guide vanes and in the wheel buckets, the expansion is confined to the guide vanes in the Hamilton-Holzwarth type, thus resembling the Rateau and Zoelly types in this respect. The Hamilton-Holzwarth also differs from the Parsons, and resembles the Rateau and Zoelly types, in having distinct wheels for each set of blades.

The following diagram, Fig. 207, is taken from a publication issued by the Hooven-Owens-Rentschler Company, of Hamilton, Ohio, who are the manufacturers of the Hamilton-Holzwarth turbine. From the diagram it is seen that the steam pressure decreases in each set of guide blades, but remains constant during the passage of the steam from one side to the other of each set of wheel blades. The velocity alternately increases and decreases in the guide blades and wheel blades.

The Turbine Wheel.—One feature in which the Hamilton-Holzwarth turbine differs from most others consists in the built-up wheel. Drawings of a wheel are shown in Fig. 208. These and the other drawings in this chapter have been kindly furnished to us by the manufacturers, and relate chiefly to a 1000 kilowatt 1500 revolutions per minute set exhibited in the St Louis Exposition of 1904. This set has a normal rated capacity of 1000 kilowatt, and a maximum capacity of 1500 kilowatt. The dynamo is a Bullock 3 phase, 25 cycle, 1500 revolutions per minute, 6600 volt alternator.

The turbine portion of the unit up to the coupling with the dynamo shaft is 24 feet 3 inches long, 7 feet 3 inches wide, and 7 feet 8 inches high, and weighs 114,000 lbs. The entire unit,

including generator, is 40 feet 2½ long and 9 feet 8 inches wide, and weighs 190,000 lbs. The turbine is designed for an admission pressure of 14 absolute metric atmospheres and a vacuum of 93·5

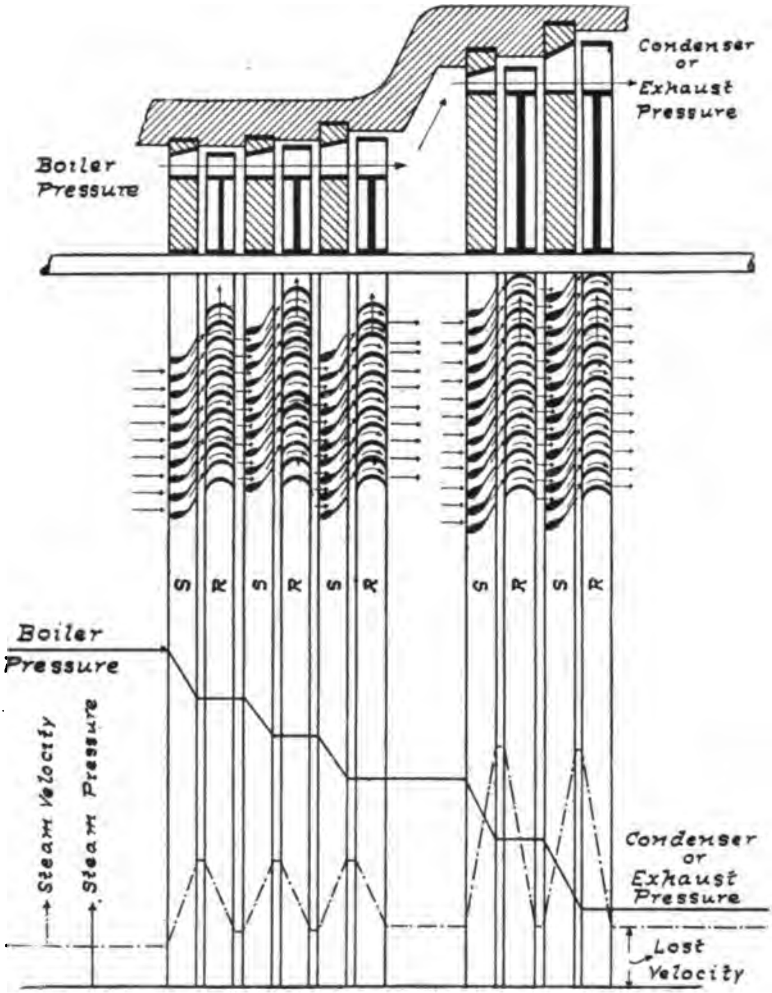


Fig. 207.—Hamilton-Holzwarth's Theoretical Diagram of Changes in Pressure and Velocity.

per cent. (28 inches of mercury). The design appears to have altogether some 32 wheels, and, say, a mean of 150 blades per wheel, or a total of 4800 vanes. This gives about 0·21 kilowatt per vane.[1] The diameter of the largest wheel appears to be

[1] We have seen in Chapter IV. that in a 750 kilowatt set of the Parsons type there are some 30,000 vanes, or 0·05 kilowatts per moving vane.

about 3·1 metres, giving a peripheral speed of 240 metres per second. It is noteworthy that the number of wheels and blades is comparatively large, yet it is far below the number employed in the Parsons type.

It is seen from Fig. 208 that the running wheel comprises steel discs riveted to both sides of a cast-steel hub, which is mounted upon and splined to the shaft. The vanes are held to the steel discs by means of rivets passing through the discs and through extensions from the vanes, which are gripped between the discs. A thin steel band is tied around the wheel at the outer end of the vanes, and this band constitutes an outside wall to the

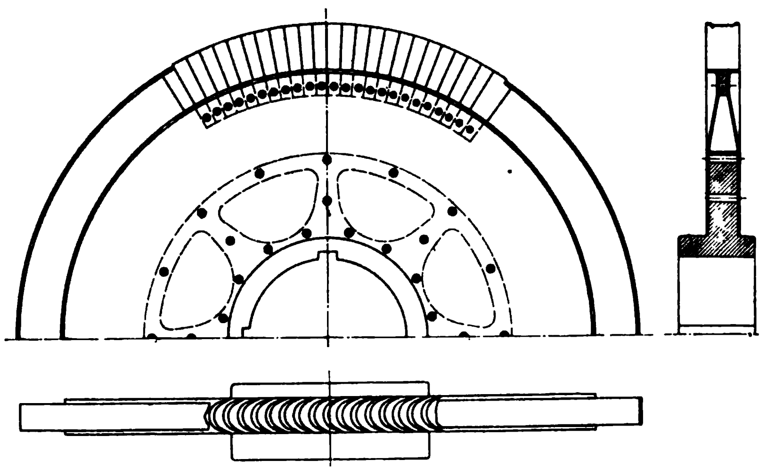


FIG. 208.—Revolving Wheel.

steam passages. Fig. 209 illustrates the design of wheel indicated in Holzwarth's U.S.A. patent No. 752340, of February 16th, 1904. This figure also well illustrates the construction of the vanes or buckets. These are lune-shaped and hollow, so as to reduce their weight. They are milled on both edges. It is stated that tests show that when mounted on the rim of the wheel as indicated, a blade will withstand a pull of 400 kilograms. Each wheel is independently balanced to well within 2 grams.

The wheels have been designed throughout with a view to light construction. This permits of the use of a shaft of relatively small diameter, and a proportionately small bore for the stationary discs, with consequent reduced opportunity for leakage of steam from stage to stage without passing through the vanes.

The Stationary Discs.—The construction of the stationary

discs is illustrated in Fig. 210. The discs are set in grooves in the turbine casings, the latter being horizontally split as in the Parsons type. But while the stationary blades belonging to the

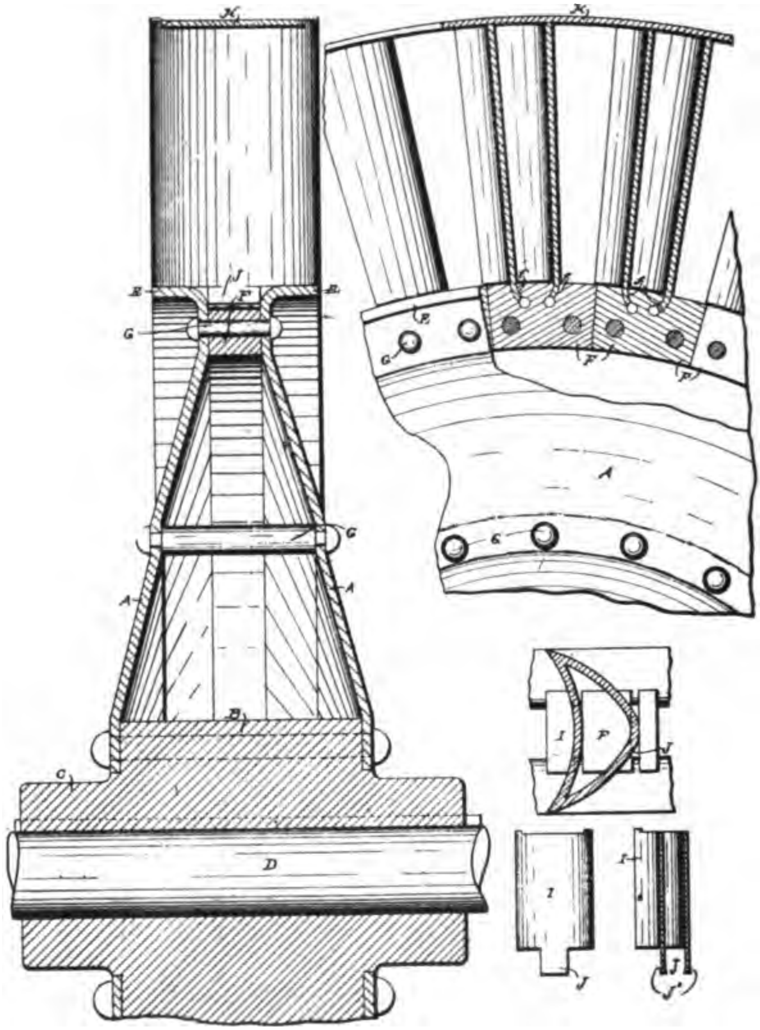


FIG. 209.—Holzwarth Turbine. U.S. Patent 752,340, Feb. 16, 1904.

upper half of the turbine are lifted with the upper half of the casing in the Parsons turbine, the rings holding the stationary blades remain in place in the Hamilton-Holzwarth type. The vanes are of drop forged steel of the shape indicated in Fig. 210. They are, of course, of increasing radial height in successive discs,

to provide for the gradual expansion of the steam. They are secured by rivets in a groove in the outside periphery of the discs, and are milled to secure the necessary accuracy of spacing and of angles.

The disc and vanes are ground on their outside edges to the correct profile, and then a tough steel ring is shrunk on the outside periphery. This steel ring constitutes the means by which the disc is fitted into the grooves in the casing.

The diameter of the bore of the stationary disc exceeds that of the hub of the running wheel by as small a clearance as practicable, so as to reduce the leakage of steam.

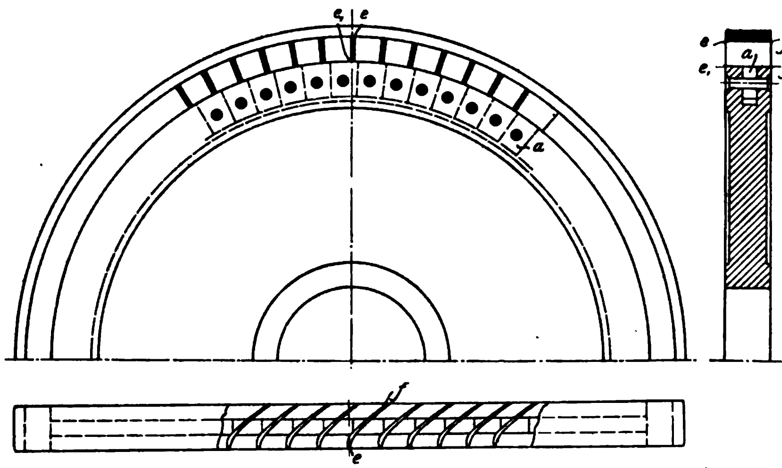


FIG. 210.—Fixed Disc of Hamilton-Holzwarth Turbine.

The 1000 kilowatt set exhibited at St Louis is illustrated in Figs. 211 to 214. In this design, as in all sizes from 750 kilowatts upwards, high and low pressure casings are provided.[1]

Separate bed plates are provided for each casing, and still another for the dynamo. These three bed plates are bolted rigidly together. All steam, oil, and water piping, including the steam inlet, regulating and by-pass valves, are within and below the bed plate.

The steam first passes through the steam separator which is placed below the bed plate, and then arrives at the main inlet valve, which is controlled by a hand wheel located above the engine-room floor at the high-pressure end of the turbine. The steam next passes through the regulating valve and then through a curved

[1] Smaller units have but a single casing.

FIG. 211.—Hamilton-Holzwarth Steam Turbine Direct-connected to 1000 K. W. Generator.

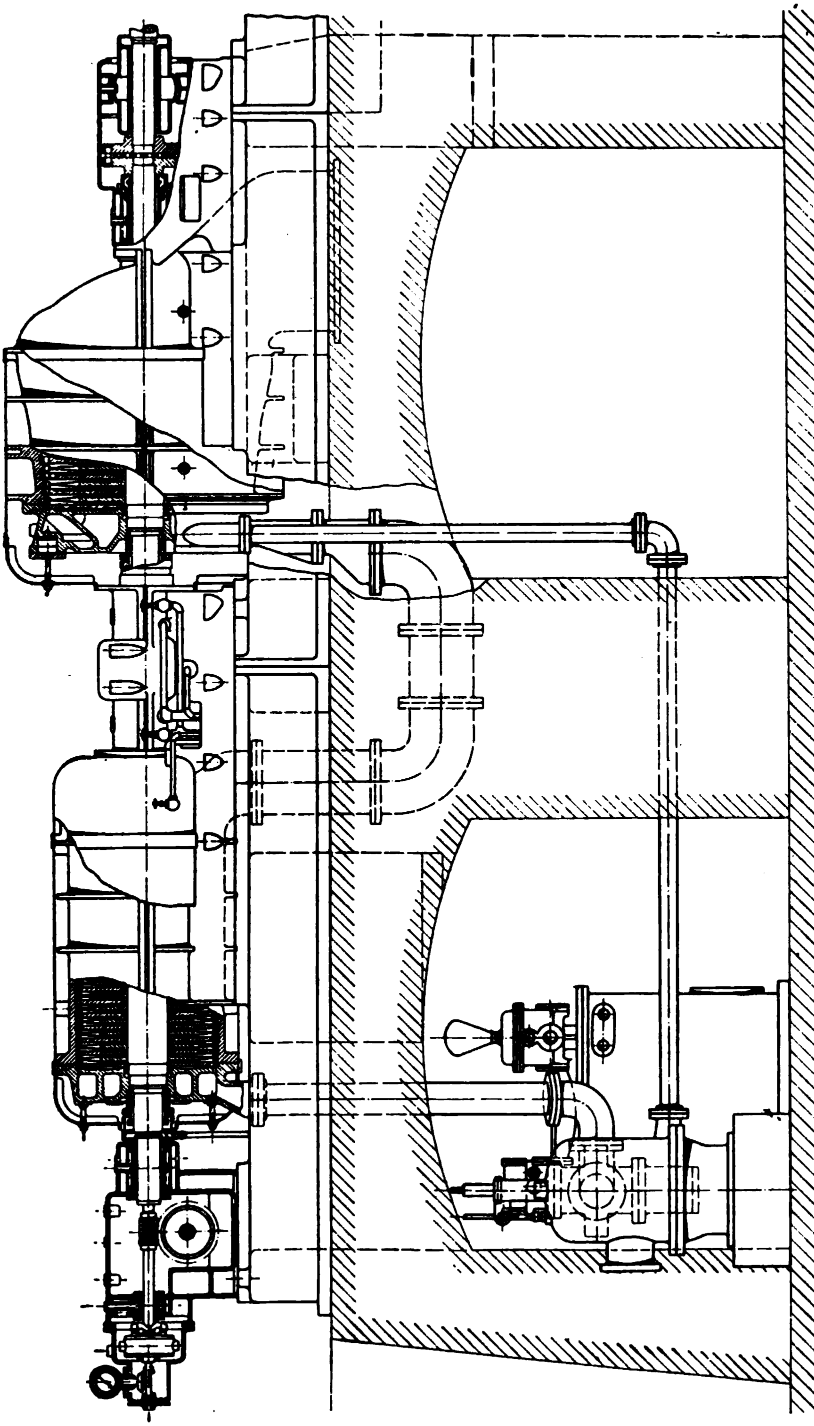


Fig. 212.—Hamilton-Holzwarth Steam Turbine Direct-connected to 1000 K.W. Generator.

pipe to the high-pressure end of the turbine. From the ring channel in the turbine head the steam reaches the first set of stationary vanes, which are rigidly connected to the head. From here the steam flows in a full cylindrical belt through the successive stages and to the condenser.

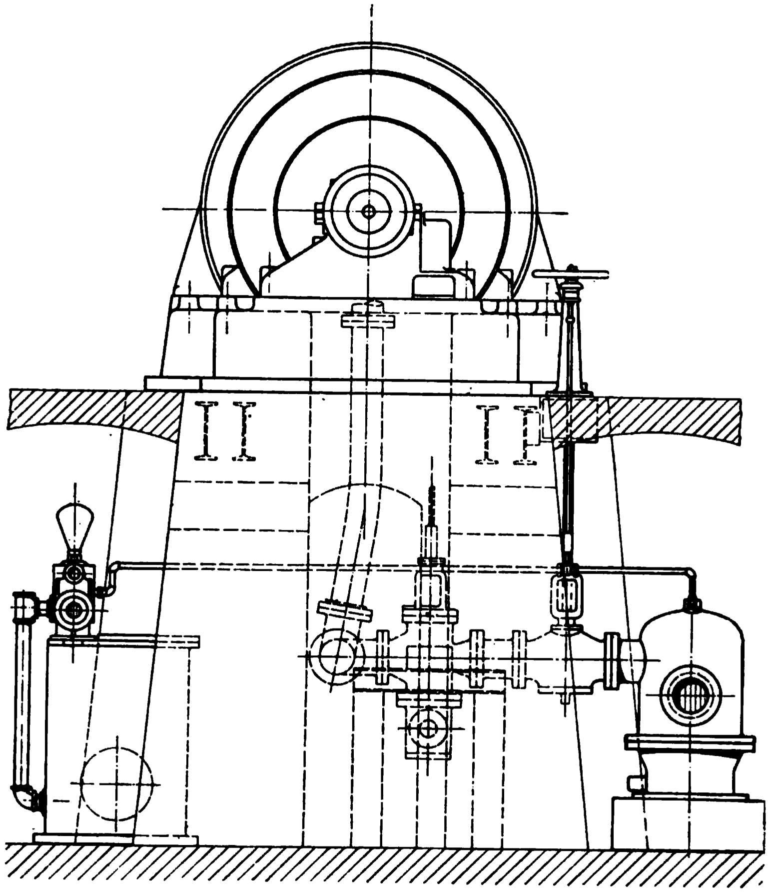


FIG. 213.—End View of Fig. 212.

It is arranged that the high-pressure steam, when admitted directly to the low-pressure casing for temporary overloads, shall have an injector action, dragging along with it the low-pressure steam from the last stage of the high-pressure casing, instead of building up a back pressure at that point. This by-pass arrangement is controlled by the governor.

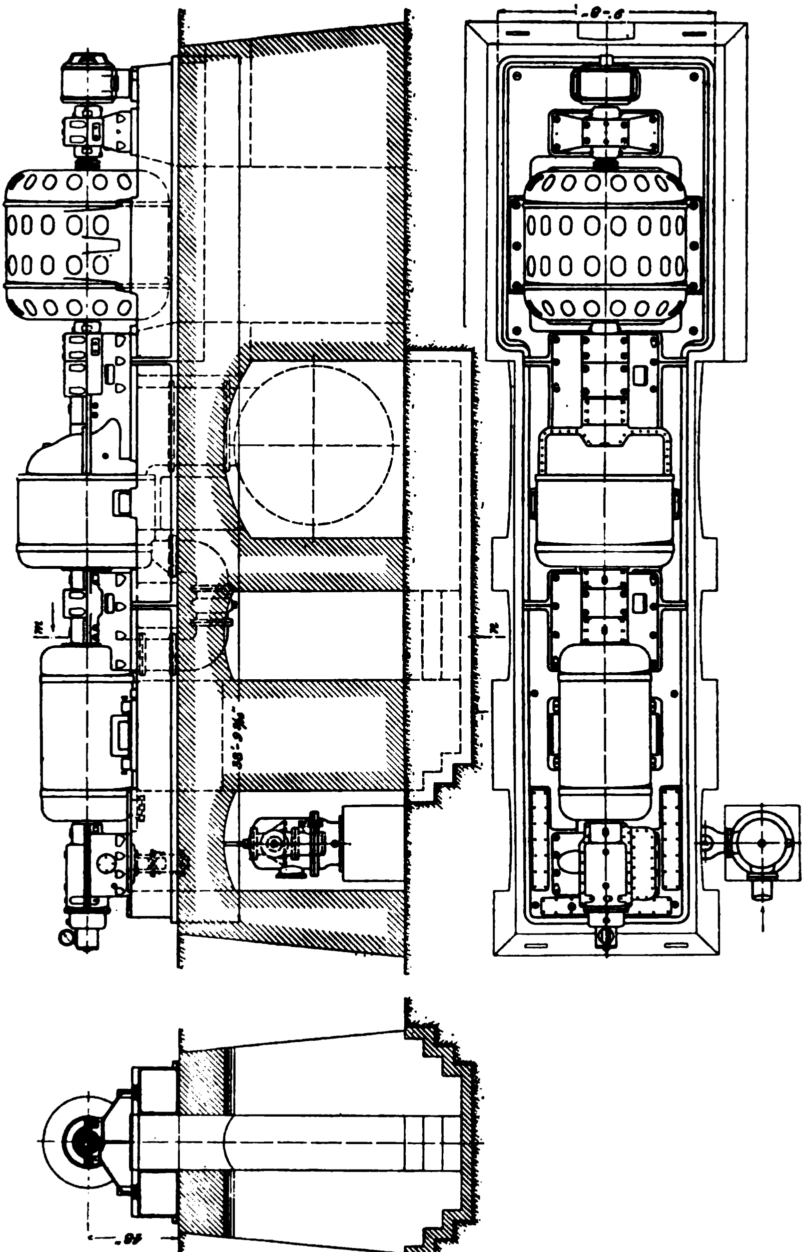


FIG. 214.—Hamilton-Holzwarth Steam Turbine Direct-connected to 1000 K.W. Generator.

Overall length, 40ft. 2½in. Width over turbine bed plate, 7ft. 8in.
Centre of coupling to end of turbine, 25ft. 5¾in. Height of turbine bed plate, 2ft. 1in.
Centre of coupling to end of bed plate, 24ft. 8in. Height of shaft centre above bed plate, 1ft. 11in.
6600 volts, 3 phase, 25 cycles, 1500 R.p.m.

Shafts and Bearings.—A unique feature of the Hamilton-Holzwarth turbine is the subdivision of the shaft. Thus in the

1000 kilowatt set the shaft is in three sections, connected by flexible couplings. This arrangement permits of independent expansion and contraction under the influence of temperature. With further reference to this point, the casings are not fastened to the bed plate. The turbine shafts and casings are held rigid only at the exhaust ends by means of the high-pressure and low-pressure pedestals respectively. Thus they can expand in the direction opposite to that in which the steam flows. At the intake ends of the two casings there are no rigid connections. There is hardly any axial thrust on the wheels, as the expansion of the steam occurs in the fixed vanes only. Any small thrust present is taken up by a thrust ball bearing. By means of this bearing the shaft may be moved in an axial direction in order to adjust the relative positions of ring wheels and stationary discs. Owing to the use of the flexible couplings, each shaft can be thus adjusted by itself without affecting the location of the other shafts. The three shafts belonging respectively to the high-pressure casing, the low-pressure casing, and the dynamo are each proportioned in accordance with the requirements. Owing to the lightness of the wheels the two former shafts are of relatively small diameter, whereas the shaft to the dynamo is larger because of the very considerable weight of the rotor.

The design of flexible coupling employed between the different sections of shaft is of interest. It was required that this coupling should easily transmit the turning moment, stand the high angular velocity, and allow ample clearance for shifting and moving the coupled shafts in axial and radial direction. Each half of the coupling consists of a disc, secured upon the end of the shaft by means of keys. The discs are fitted near their outer circumference with projecting teeth, consisting of steel laminations. The teeth of one disc fit between the corresponding teeth of the other disc, so that a number of pairs of brushes distributed around the circumference are always flexibly engaged in either direction of rotation. It is stated by the manufacturers that this coupling is suitable for any practical angular velocity and for the transmission of large powers.

Stuffing Boxes.—The stuffing boxes used at each end of each casing are illustrated in Fig. 215. The design is based upon the principle that a shaft revolving in a box of sufficient length and with small clearance throttles any escaping steam. Instead of providing a long box, the required length of leakage surface is obtained by the telescopic construction shown in Fig. 215.

A ring fastened to the shaft and revolving with it extends axially into the deep groove of another ring which does not revolve. The stationary grooved ring presses against the adjoining bearing bushing. The space between this ring, the bushings, and the shaft is connected with a drain pipe on the pressure side and a water pipe on the vacuum side. By this means it is impossible for steam to leak along the shaft.

The bearings for the turbine shaft are made with cylindrical shells, but those for the generator shaft, having greater weight to carry, have spherical shells to ensure their alignment.

The pedestals and caps of the bearings are arranged so that the oil inlet and outlet are placed close together, and none of the piping

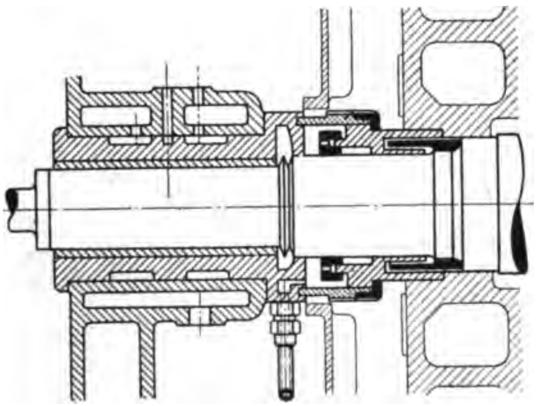


FIG. 215.—Stuffing Box.

has to be deranged to take out the bushings. The oil flows to the bottom bushing under a slight pressure and is led off through the cap to the oil outlet in the pedestal. It is stated that the dimensions of the bearings are such that they can be guaranteed to run cool without any risk.

Governor.—Fig. 216 shows the arrangement of the governing mechanism. The worm on the turbine shaft W keeps the disc *m* revolving. The position of the centrifugal governor M on the end of the turbine shaft fixes the point of contact of the friction wheel *e* on the rotating disc *m*. When on one side of the centre of *m* the rotation of *e* closes the valve on spindle *a*, on the opposite side of the centre of *m* it opens the valve; on the centre it produces no movement; also the spring-controlled lever *gk* holds disc *m* out of contact with *e* at this position.

The speed of the valve's motion depends on the distance of the contact from the centre of *m*.

If the speed exceeds the normal by 2·5 per cent., the spring balance *p* shuts off steam.

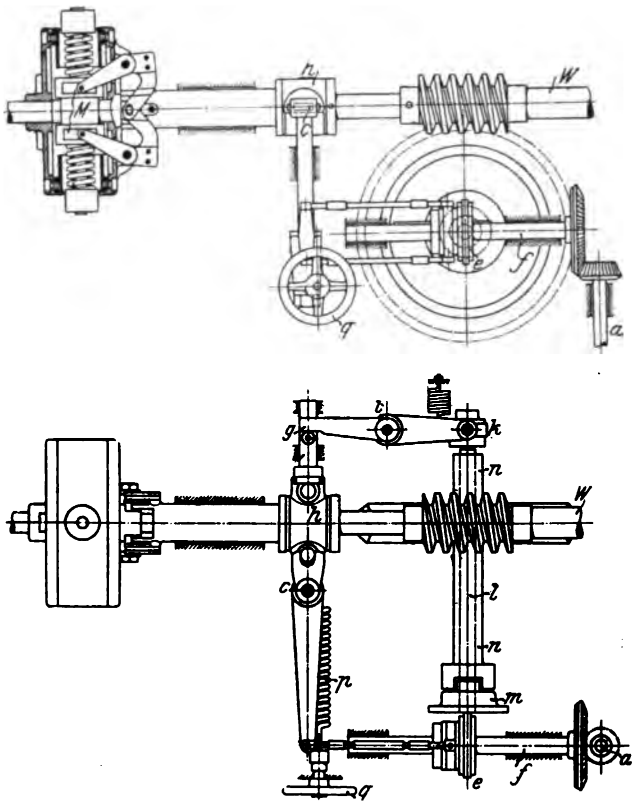


FIG. 216.—Governing Mechanism. Position with Turbine at Normal Speed.

W, turbine shaft.
f, spindle which actuates valve on *a*.
a, valve spindle.
n, hollow shaft fixed to worm wheel.
l, spindle carrying *m*.
m, friction disc.
c, friction wheel sliding on feather in *f*.

(From *Zeitschrift d. V. d. I.*, Jan. 28, 1905, and U.S.A. Patent 761966, 1904.)

Lubrication.—A pump driven off a worm on the main shaft supplies oil under pressure and forces it through a strainer and cooler after it has passed through the bearings.

TABLE LXXXVII.—LIST OF HAMILTON-HOLZWARTH STEAM TURBINES. DIRECT-COUPLED WITH GENERATORS.

Size in K.W. Rated.	Size in K.W. Max.	Speed R.p.m.	Type.	No. of Casings.	For Coupling with "AC" or "DC" Generators.	No. of Cycles.	Approximate Weight of Turbine, Bed, and Pedestal for one Generator.	Approximate Weight of Turbine, Bed, and Pedestal for two Generators.	Required Space of Turbine. Extreme Length up to C of Coupling. ft.	ins.	Extreme Width. ft.	ins.	Extreme Height. ft.	ins.	Required Space of whole Unit. Approximate Dimensions. Extreme Length. ft.	ins.	Extreme Width. ft.	ins.	Extreme Height. ft.	ins.
							lbs.	lbs.	ft.	ins.	ft.	ins.	ft.	ins.	ft.	ins.	ft.	ins.	ft.	ins.
100	300	3600	Noncondensing	1	AC	60	12,000	...	10	0	4	2	4	4	17	6	4	2	4	4
100	300	3600	Condensing	1	AC	60	15,500	...	11	6	4	2	4	4	19	0	4	2	4	4
100	300	2400	Noncondensing	1	DC	...	19,700	23,300	9	6	6	8	5	7	1 gen. 16 2 gen. 21	2 7	6	8	5	7
100	300	2400	Condensing	1	DC	...	29,000	33,000	13	6	6	8	6	0	24	0	6	8	6	0
400	800	1800	Condensing	1	AC	60	60,000	...	14	3	7	3	6	10	26 30	0 0	7 8	3 6	6 7	10 6
400	800	1500	Condensing	1	AC	25	64,000	...	15	0	7	3	6	10	26 30	9 0	7 8	3 6	6 7	10 6
1000	1800	1800	Condensing	2	AC	60	102,000	...	26	0	7	3	7	8	41 43	0 0	7 9	3 8	7 8	8 6
1000	1800	1500	Condensing	2	AC	25	114,000	...	26	7	7	3	7	8	41 43	6 0	7 9	3 8	7 8	8 6

CHAPTER XI

THE ELEKTRA STEAM TURBINE

The Elektra Steam Turbine will be understood by reference to the drawings in Fig. 217, and the photograph in Fig. 218, which shows the parts of a 50 horse-power turbine. The turbine is at present built only in sizes of from 10 to 300 horse-power rated output, but it is the intention of the Gesellschaft für Elektrische Industrie of Karlsruhe to develop designs for larger sizes. It is pointed out by the manufacturers to whom we are indebted for our information that the Elektra turbine runs at moderate speeds without the need of reduction gearing, as in the de Laval type, on the one hand, and without the employment of wheels of large diameters and high peripheral speeds, as in the Riedler-Stumpf and other types, on the other hand. Like both of these types, the Elektra turbine in its simplest form has but a single running wheel, and in this respect differs from the Parsons, Rateau, Zoelly, and the other multiple wheel turbines.

The relatively low speed is obtained by utilising four successive impacts of the jet of steam against the vanes of the running wheel in passing from the admission nozzle to the exhaust outlet. The energy of the steam is transformed by expansion in the nozzle into kinetic energy, a part of which is delivered to the vanes of the wheel at each impact.

A casing, in which are cast two concentric steam passages *p* and *q*, surrounds the working parts. The steam is admitted by the passage *p*, and after performing its work, leaves the turbine by the passage *q*. The steam arriving by *p* is discharged against the vanes of the wheel through the two nozzles. The steam rebounds from the vanes into the first of the reversing passages *g*, and is therein guided for a second time against the vanes of the wheel. This process is continued until, after several (usually four) impacts,

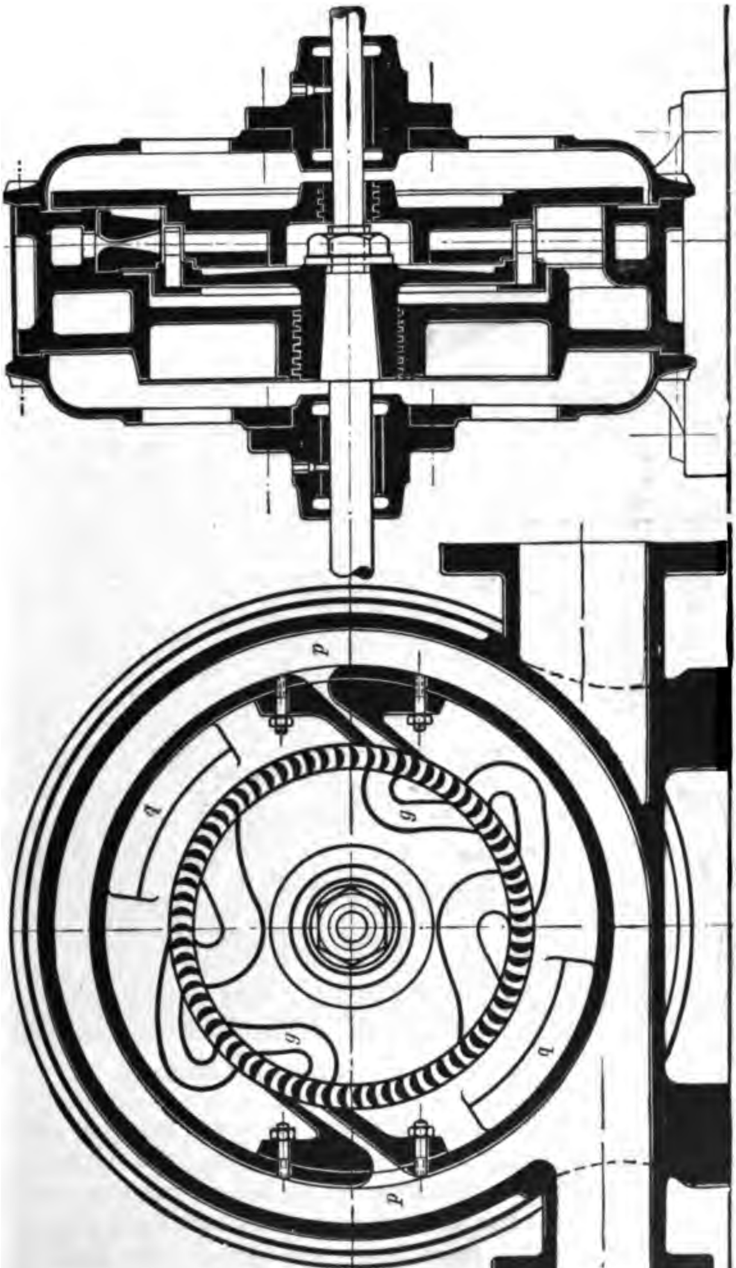


FIG. 217.—50 Horse-power Elektra Steam Turbine.
(*Gesells. f. Elek. Ind.*)

it flows off to the outlet q. The passages from p to q are gradually increased in section to correspond with the increasing volume and decreasing speed of the steam.

Construction. Peripheral Speed and Clearance.—The general construction of the turbine wheel may be understood by

FIG. 218.—50 Horse-power Elektra Steam Turbine.

reference to the illustrations. The steel vanes are mounted on a wrought-iron or steel disc, and are held in place by a press-ring. The peripheral speed is only from 80 to 100 metres per second (260 to 330 feet). As the steam flows radially back and forth over the vanes of the wheel, there is no end-thrust. The clearance between the running vanes and the stationary nozzles is about 3 millimetres.

The manufacturers have supplied us with the data comprised in Table LXXXVIII. These guarantees relate to the single-wheel type, which is made in capacities up to and including 100 horse-power.

TABLE LXXXVIII.—SINGLE-WHEEL ELEKTRA TURBINES.

Rated Output in Horse-power.	Rated Speed in R.p.m.	Guaranteed Steam Consumption in Kgs. per Horse-power Hour[1] and an Absolute Admission Pressure of 11 Kgs. per sq. cm.			
		Non-Condensing.		Condensing,—90% Vacuum.	
		No Superheat.	Superheat = 50° Cent.	No Superheat.	Superheat = 50° Cent.
10	4000	23	20·5	15	13·5
15	4000	22	19·5	14·5	12·5
20	3500	20	18	13·5	12·0
30	3500	19	17	12·5	11·5
50	3000	18	15·5	12·0	11·0
75	3000	17	14·5	11·5	10·0
100	3000	15·5	13·5	10·5	9·5

[1] Table LXXXIX. gives these values per K.W. hour.

For sizes of 30 horse-power and greater, the manufacturers provide, when desired, a compound type with two running wheels. The designs for 150, 200, and 300 horse-power appear to be built exclusively in the two-wheel type.

In Table LXXXIX. are given the manufacturers' guarantees for the single-wheel type up to and including the 30 horse-power size, and for the double-wheel type for the larger sizes. In this table the results are expressed in terms of the steam consumption in kilograms per kilowatt-hour output from a dynamo direct-connected on the turbine shaft.

Some further data of the single-wheel designs has very kindly been furnished us by the manufacturers, and is set forth in Table XC.

The manufacturers report that the turbine is provided with means whereby, when the machine must operate for a considerable time at light loads, a considerable economy can nevertheless be obtained. When this means is employed, the steam consumption per kilowatt-hour of output at light loads will exceed that at rated full load by the percentages set forth in the second column of Table XCI. For fluctuating loads this means cannot be employed, and the corresponding increase in steam consumption is then as shown in the third column of the table.

TABLE LXXXIX.—SINGLE- AND DOUBLE-WHEEL ELEKTRA TURBINE SETS, COMPRISING A DIRECT-CONNECTED GENERATOR.

Rated Output. In H.P. from Turbine Shaft.	Rated Output. In K.W. from Dynamo.	Rated Speed in R.p.m.	No. of Wheels.	Guaranteed Steam Consumption in Kgs. per Kilowatt-hour. Absolute Admission Pressure = 11 Kgs. per sq. cm. Superheat = 50° Cent. Vacuum = 90 per cent.	Corresponding Values inferred for Absolute Adm. Pressure of 13 Kg. Superheat = 50° Cent. Vacuum = 86·6 per cent. (The "Standard" conditions adopted throughout this treatise).
10	6·3	4000	1	20·4	20·8
15	9·6	4000	1	19·2	20·3
20	13·0	3500	1	18·2	18·6
30	19·7	3500	1 and 2	17·4 (and 12·8 for the 2-wheel type)	17·2 (and 13·4 for the 2-wheel type)
50	33·3	3000	2	12·4	12·9
75	51·0	3000	2	11·8	12·2
100	68·0	3000	2	11·5	11·8
150	100	3000	2	11·2	11·5
200	135	3000	2	10·6	10·9
300	200	3000	2	10·0	10·4

TABLE XC.—SINGLE-WHEEL ELEKTRA TURBINES.

Rated Output in Horse-power.	Rated Speed in R.p.m.	Weight in Kilograms.	Diameter of Wheel in mm.	Peripheral speed in m.p. sec.	No. of Vanes on Wheel.	Horse-power per Vane.	Diameter over Casing in mm.	Length from Outer End of Regulator to Middle of Coupling.
10	4000	275	300	63	235	0·042	600	750
15	4000	325	300	63	235	0·063	600	800
20	3500	400	400	73	310	0·065	800	950
30	3500	600	400	73	310	0·097	800	1050
50	3000	900	525	83	400	0·125	1150	1350
75	3000	1250	525	83	400	0·19	1150	1450
100–120	3000	1500	625	98	400	0·25	1350	1650

TABLE XCI.

Percentage Increase in Steam Consumption over that at Rated Full Load for an Absolute Admission Pressure of 11 Kgs. per sq. cm., 50° Cent. of Superheat, and a 90% Vacuum.	For a Steady Load, by means of Special Arrangement.	For a Fluctuating Load.
¼ load	10 per cent.	55 per cent.
½ load	6 per cent.	20 per cent.
¾ load	3 per cent.	7 per cent.

Dimensions.—A 50 horse-power 2-wheel turbine (exclusive of dynamo) requires a floor space of 1·3 × 1·1 metres, and has a height of 1·5 metres.

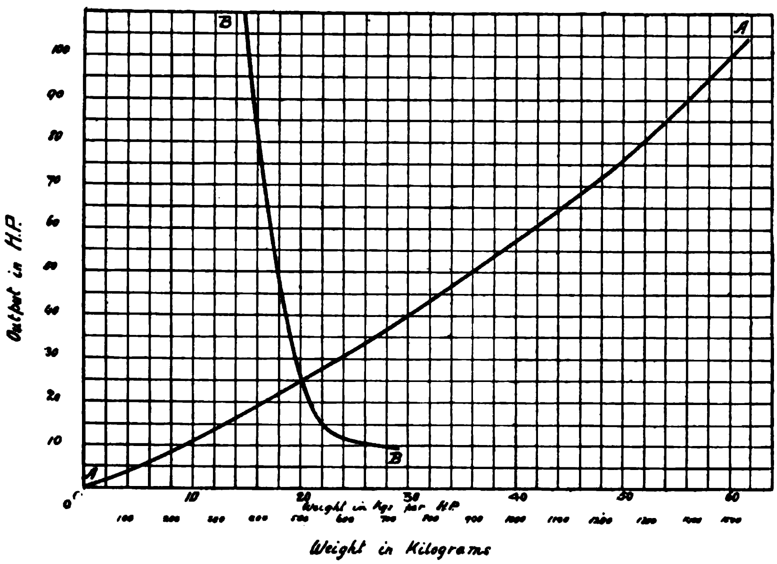


FIG. 219.—Approximate Weights of Elektra Turbines.

Curve A = Total Weights.
,, B = Weight per Horse-power Output.

Curves indicating the approximate weights of, and floor space occupied by, Elektra Steam Turbines are shown in Figs. 219 and 220.

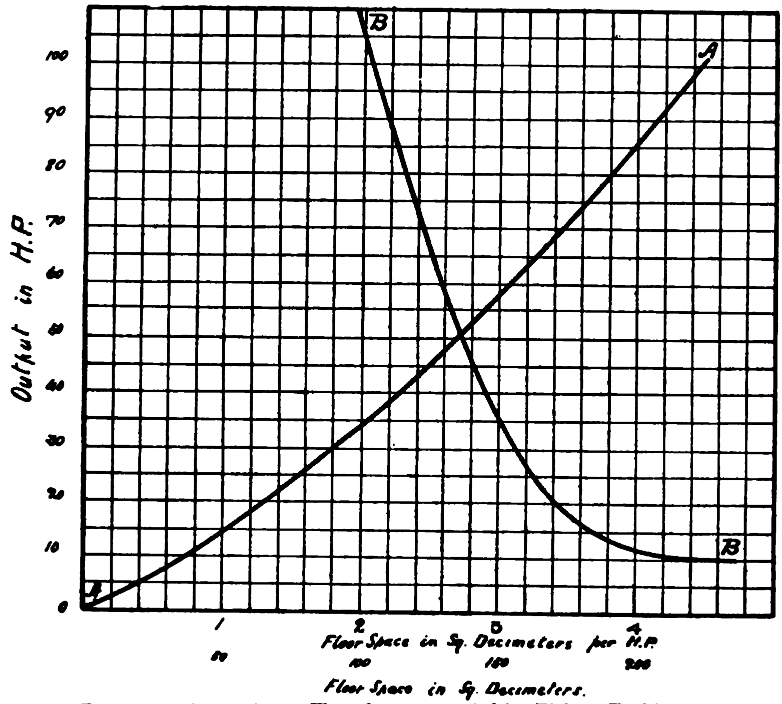
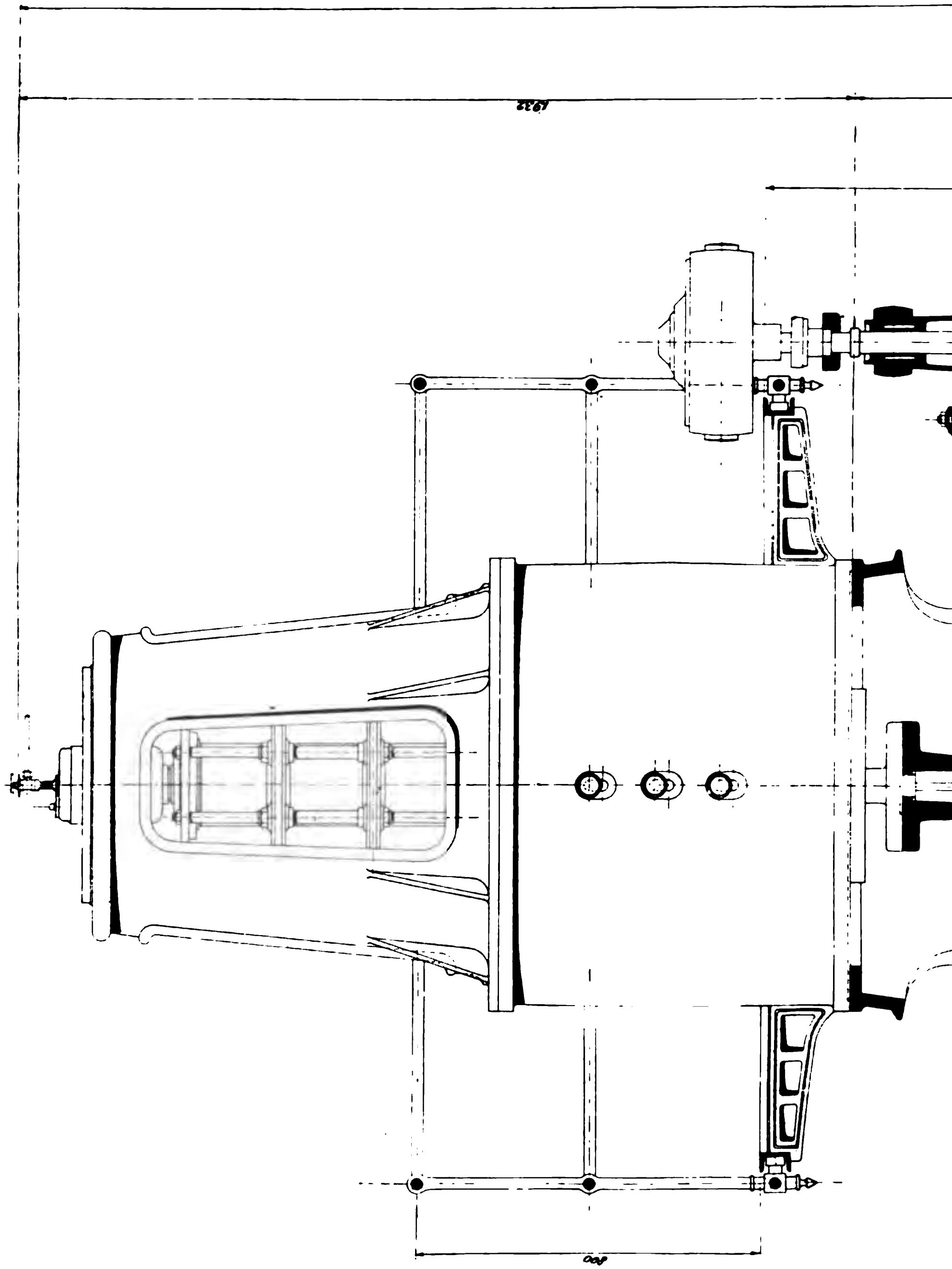


FIG. 220.—Approximate Floor Space occupied by Elektra Turbines.

A = Total (Lower Scale).
B = per Horse-power (Upper Scale).


1932
800

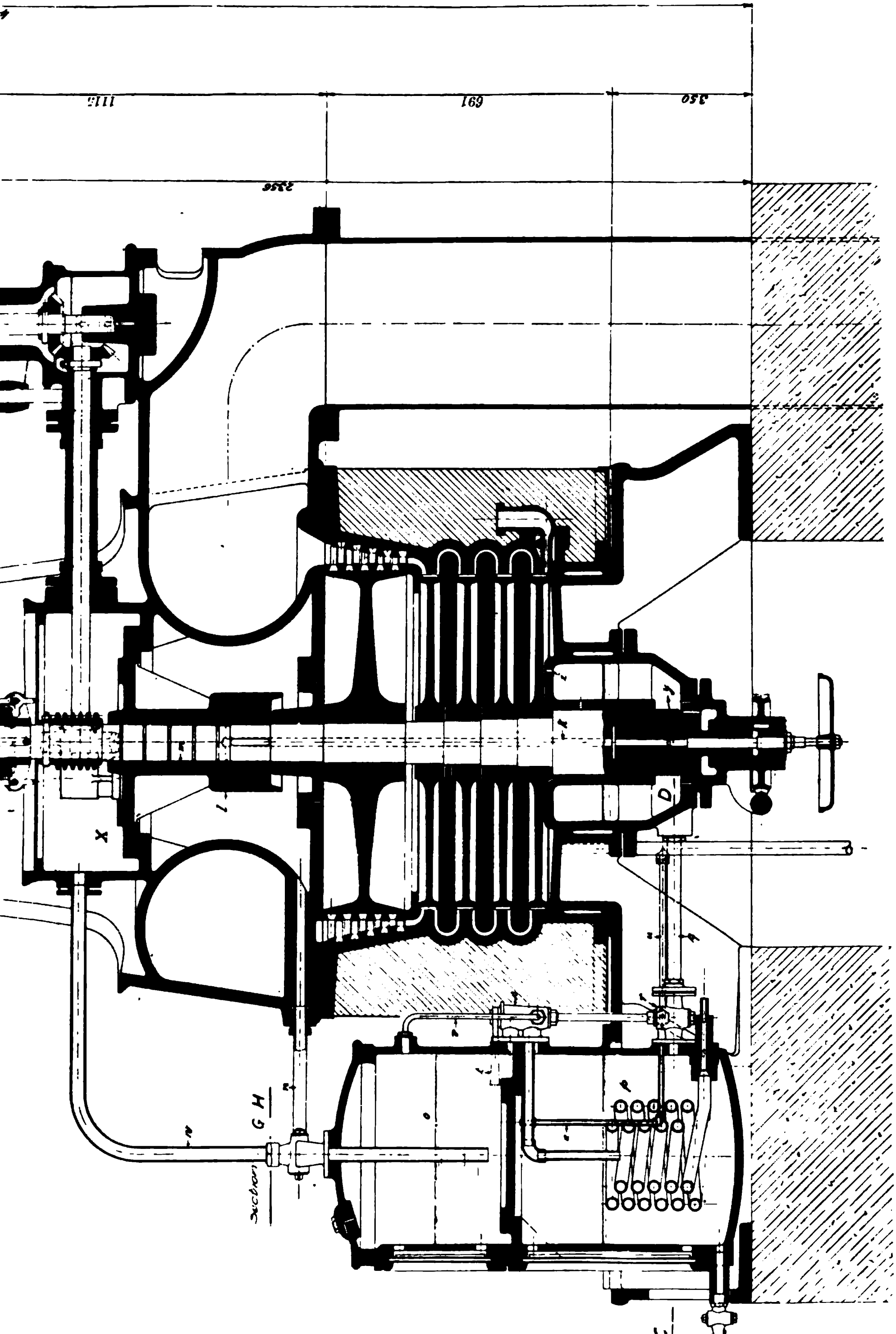


Fig. 221.—Vertical Type of Union Steam Turbine of 300 Horse-power rated capacity.

CHAPTER XII

THE UNION STEAM TURBINE

THE Union Steam Turbine is built by the Maschinenbau-Aktien Gesellschaft Union at Essen. The turbine has only recently been developed, and it is not yet extensively used; nevertheless it has been thought that it could appropriately be described as illustrative of an important direction towards which steam turbine development is tending, namely, to combine in a single design more than one fundamental method of working. The "Union" turbine is the most pronounced available example of this tendency, and it is very probable that the near future will witness extensive developments of a similar sort.

In Fig. 221, kindly furnished us by the Maschinenbau-Aktien-Gesellschaft Union, is illustrated a vertical 300 horse-power "Union" turbo-generating set.

Steam Current Upwards.—The steam is projected against the vanes of the lowest wheel of the high-pressure chamber by means of diverging nozzles directed against the lower edge of the U-shaped vanes formed in the periphery. After being rejected from the lowest wheel, the steam is successively guided to the remaining stages of the high-pressure section, each stage of which contains one wheel. The nozzles are shown in Fig. 222, and one of the wheels of the high-pressure end is shown, Figs. 223 and 224, where the vane construction is illustrated. After emerging from the last wheel of the high-pressure section, the steam flows to the low-pressure section, which contains but a single wheel, provided, however, with a number of rows of vanes, alternating in position with a corresponding number of rows of stationary vanes projecting from the surrounding casing. The low-pressure wheel which is illustrated in Fig. 225 closely follows the principle of the Parsons type, while the high-pressure wheel resembles the Rateau and

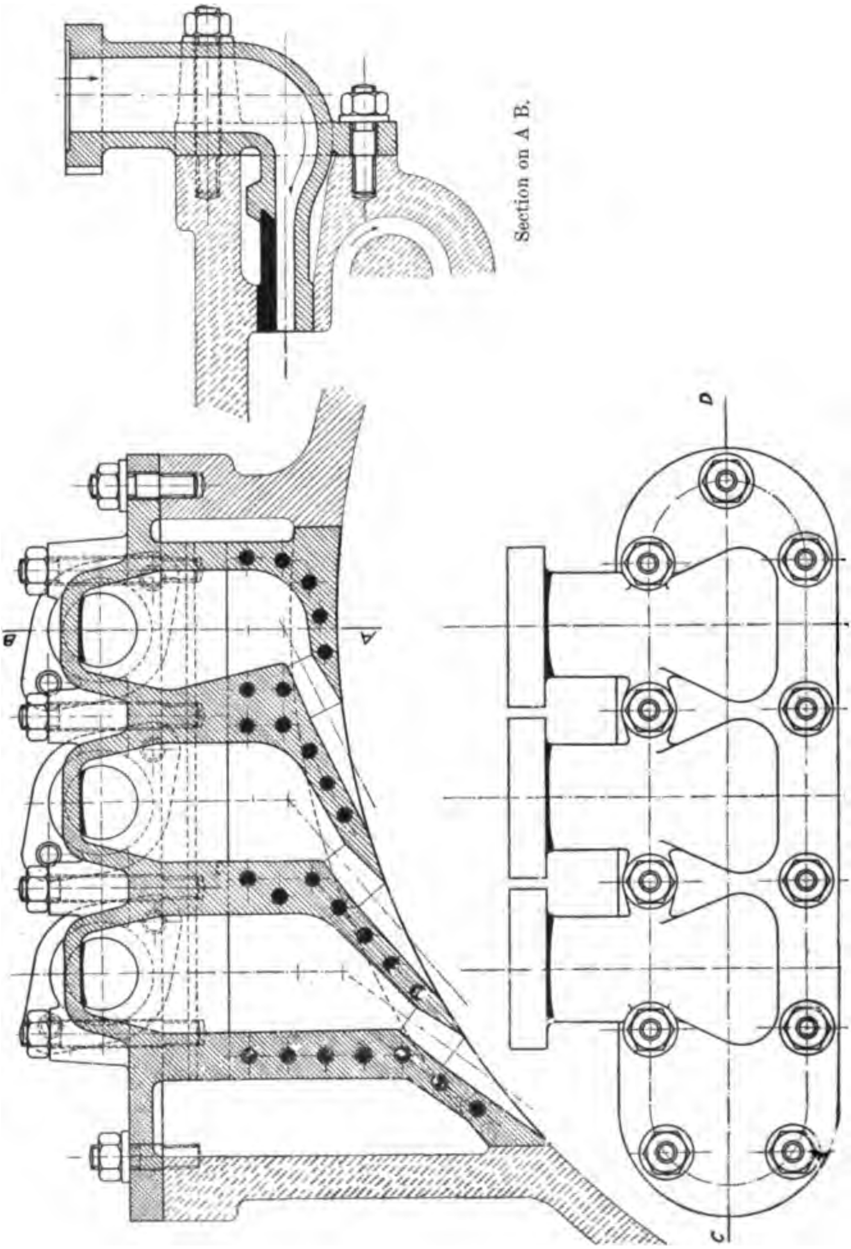
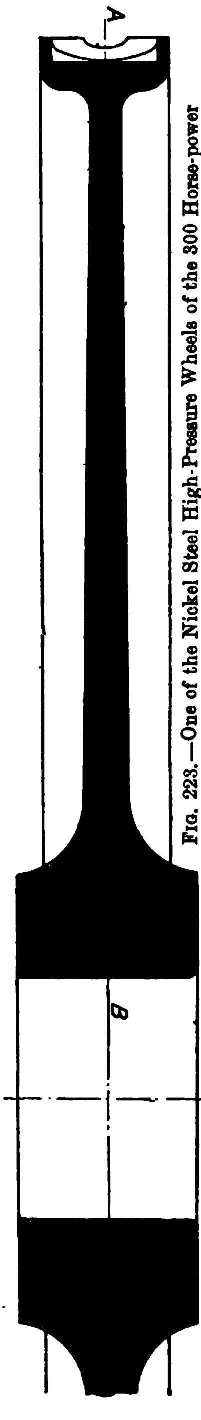


FIG. 222.—Construction of Nozzles for 300 Horse-power Union Steam Turbine.



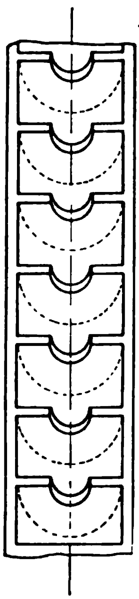


FIG. 223.—One of the Nickel Steel High-Pressure Wheels of the 300 Horse-power Union Steam Turbine, showing Vanes milled in the solid rim. Reproduced one-third original.

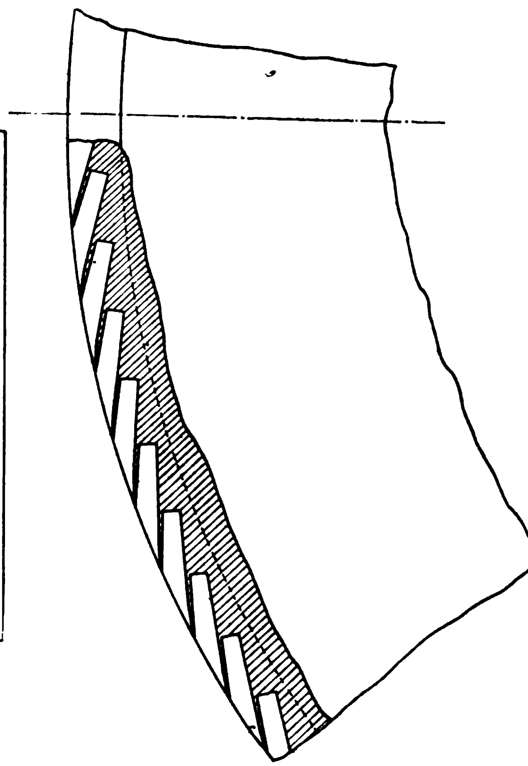


FIG. 224.—Section on A B, Fig. 223.

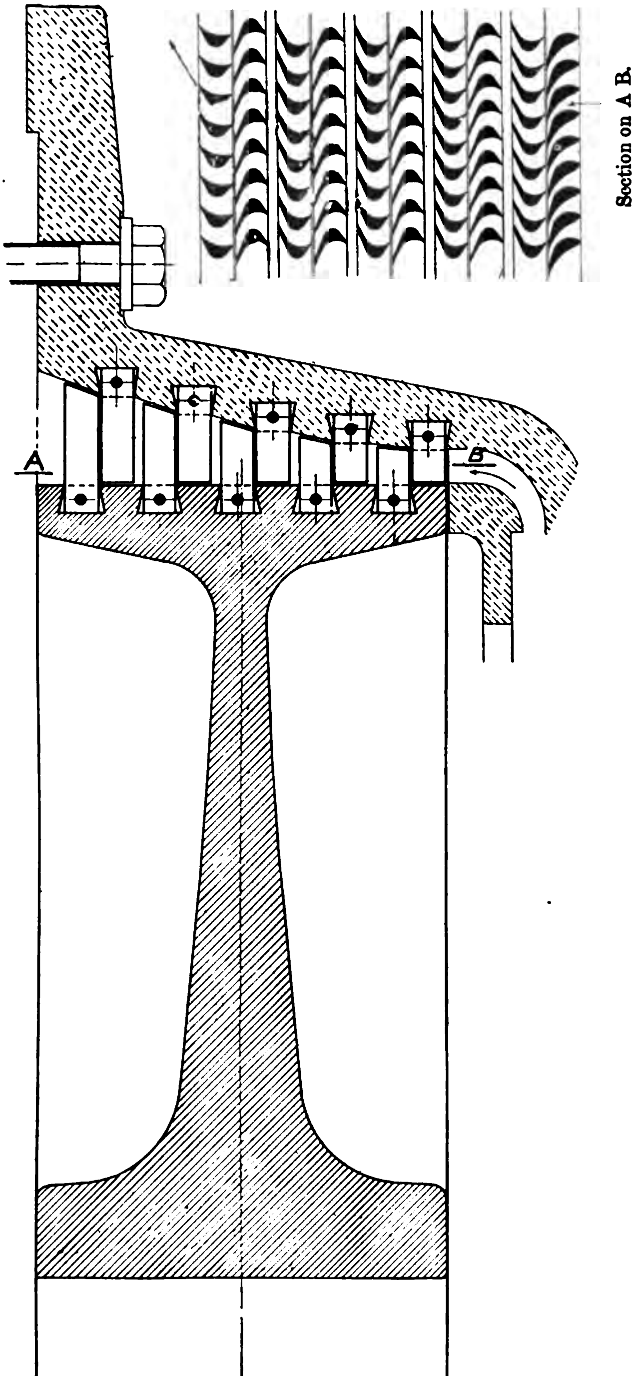


FIG. 225.—Low-Pressure Wheel of 300 Horse-power Union Steam Turbine, showing also section of surrounding Casing, with Rings of Stationary Vanes. Reproduced 1/3·66 of original.

similar types. It is interesting to note that, contrary to the plan adopted in the vertical type of Curtis turbine, the steam is admitted at the lower end, and is led away to the condenser from the upper end of the turbine casing. A photograph of the turbine wheels of this 300 horse-power set is reproduced in Figure 226.

In the smaller capacities the Union turbine is designed to utilise the kinetic energy of the steam by means of diverging nozzles, and in these designs one or more pressure stages, with one or more speed steps per pressure stage, are employed.

The employment of the Parsons principle for the low-pressure

FIG. 226.—Photograph of Wheels of Vertical 300 Horse-power Union Steam Turbine.

section only, as in the larger sizes of "Union" turbine, is, in the opinion of its designers, of advantage, in that it considerably decreases the required number of rows of blades. It is contended that the rows of blades at the high-pressure end of the Parsons turbine contribute but a relatively small proportion to the total mechanical output. The enormous number of small vanes required in these sections is in itself an objection, and it would be expected to be difficult to keep the minute passages clear from deposits.

In the Union turbine the nozzles projecting the steam upon the lowest wheel occupy two diametrically opposite sections of the periphery. In each successive wheel the nozzles cover a greater portion of the periphery, and in the case of the last wheel of the high-pressure section the steam is projected against the wheel from a

belt of nozzles occupying the entire periphery. In the low-pressure section the stationary vanes, as in the Parsons type, of course occupy the entire periphery, the vanes increasing in radial depth toward the low-pressure end, as seen in Fig. 225. A plan view of the 300 horse-power set is given in Fig. 227. The regulator is illustrated in Figs. 228 to 230. Its operation is based upon variations in the quantity of the steam, which is, of course, a function of the load, and it controls a distributing valve, which acts to admit the steam through a varying number of nozzles.

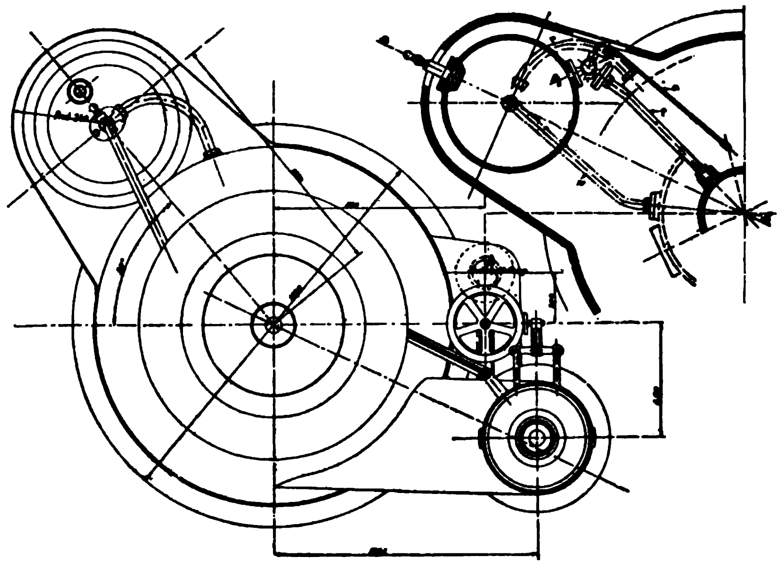


FIG. 227.—Plan of Vertical 300 Horse-power Union Steam Turbine.

Thus there is no throttling of the steam, and this contributes to high economy, as the pressure conditions, at least in the first stages, are practically the same at all loads.

A safety-regulator is also provided as shown in Figs. 228 to 230. This acts to close a quick-acting main steam valve when the speed rises to a certain point above the normal. The operation is as follows:—

A block M is capable of a slight movement along the turbine shaft by means of the pressure of the projecting arms of the weights *e*, whose position is determined by the centrifugal force corresponding to the speed. The upward movement of M brings its conical surface into engagement with the rim of the wheel

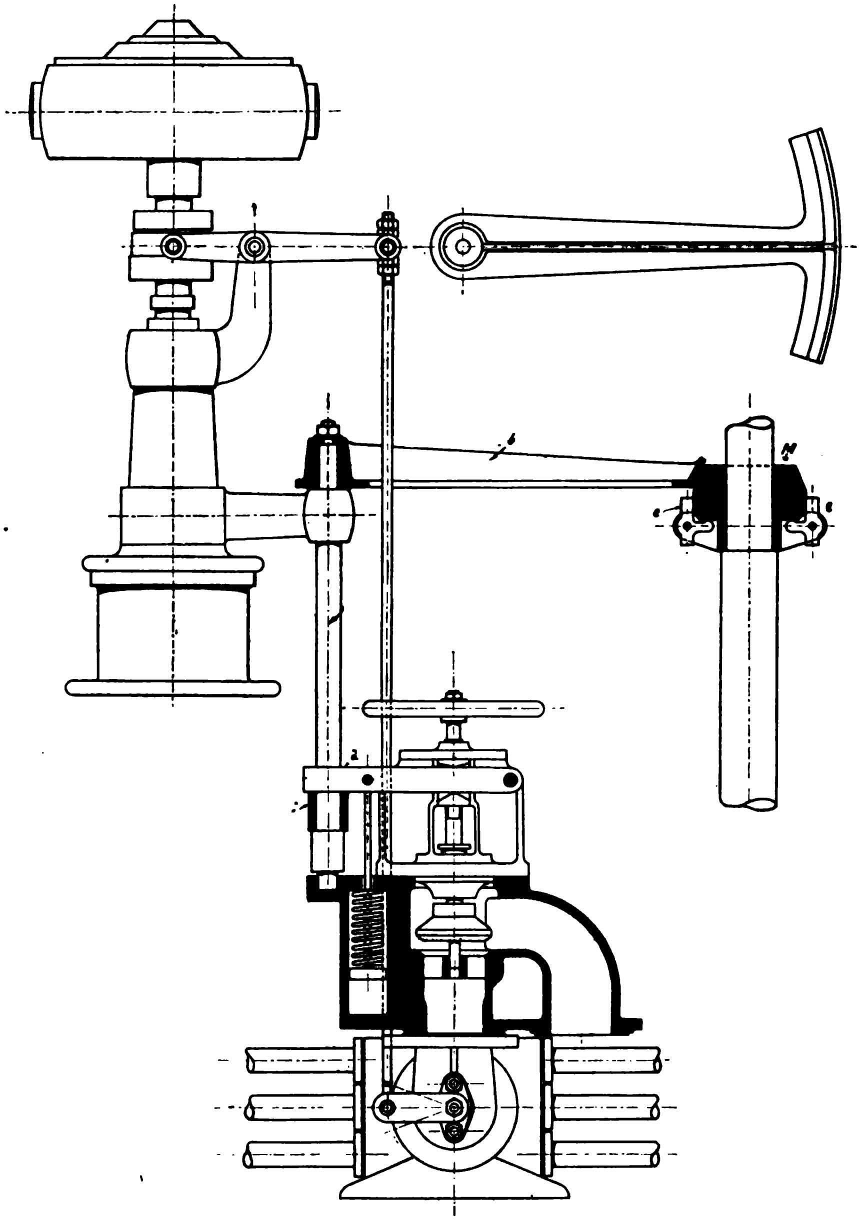
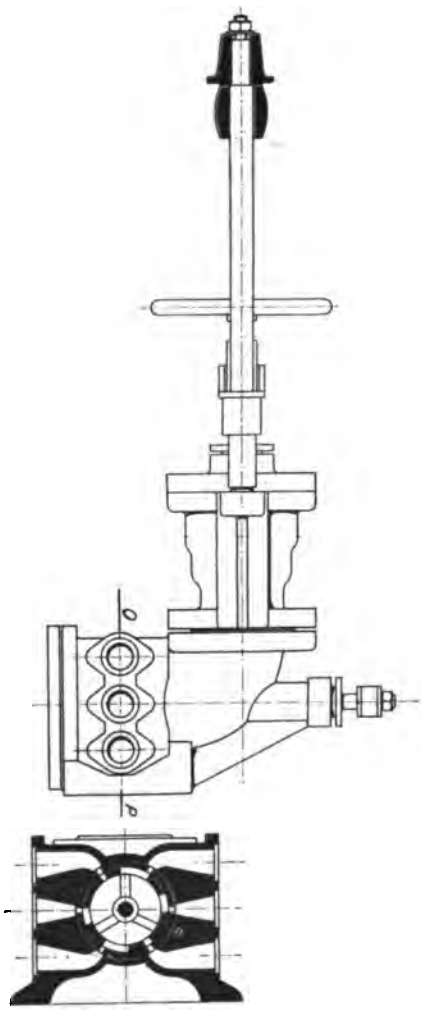


FIG. 228.—Governor and Safety-Regulator of Vertical 300 Horse-power Union Steam Turbine. Scale, 1 inch = 1 foot.

segment *b*, which, in turning, brings the support *c* into such a position that the beam *d* may be pulled down by the spring as shown, thus promptly closing the main valve.



Section on O P.

Fig. 229.—Side Elevation Safety Regulator, Fig. 228.

The safety-regulator of the horizontal type of Union turbine is shown in Fig. 231. The action in this case differs from that employed in the safety-regulator used for the vertical type, and is as follows :—

Two weights *a* are normally connected by the thin steel plate *b*. But at a certain speed the centrifugal force of the weights breaks the plate *b*, and the weights fly out and release the detent K. This causes the valve V to close instantaneously under the influence of the spring *f*.

Outline drawings of a 50 horse-power horizontal shaft Union turbine are given in Figs. 232 to 233, and a photograph of this design is reproduced in Fig. 234. This type is employed for all capacities of less than 300 horse-power.

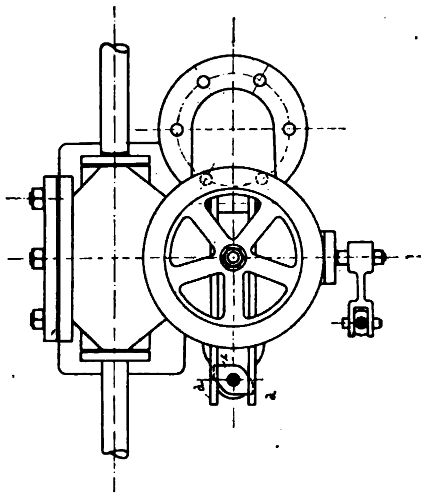


FIG. 230.—Plan of Fig. 229.

In Table XCII. are given the results of some tests made in February 1905 on a 50 horse-power two-stage Union turbine. With an absolute admission pressure of 11 kilograms per square centimetre and 65° Cent. of superheat, the consumption at rated full load amounted to 9·24 kilograms per B.H.P. hour.

From 300 horse-power upwards the Union turbines are of the same type as the 300 horse-power design already described and illustrated. The wheels are complete discs of nickel steel, and in the case of the high-pressure wheels the vanes are cut in the solid rim of the wheel. The method of overlapping the vanes is similar to that employed in the Riedler-Stumpf type. This overlapping, together with the practice of polishing the surfaces, contribute to a low wheel resistance. The factor of safety is from 7 to 8. It is claimed that, in consequence of the upward flow of the steam

in the vertical type of turbine, the weight of the rotor is almost equalised.

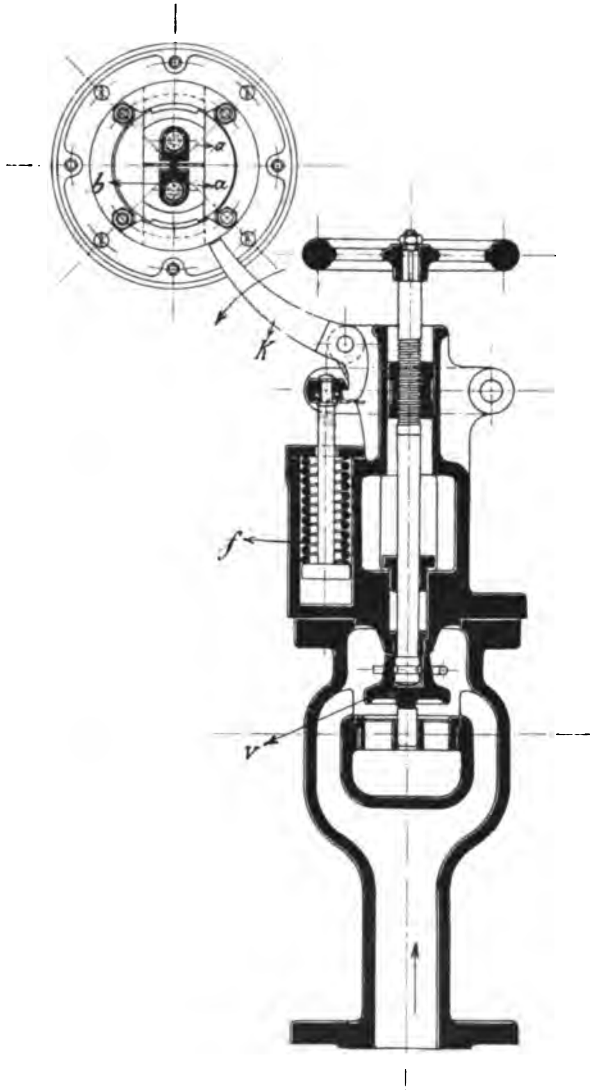


FIG. 231.—Safety-Regulator for Horizontal Type of Union Steam Turbine. Scale, 2 inches = 1 foot. Type D 30.

The authors are indebted to the courtesy of Messrs The Maschinenbau-Actien-Gesellschaft Union of Essen, the manu-

TABLE XCII.—TESTS ON A 50 HORSE-POWER TWO-STAGE UNION STEAM TURBINE.

	No Load.	¼ Load.	½ Load.	¾ Load.	Full Load.	Over Load.	Full Load and Superheating.
Absolute Steam Pressure before the Turbine. Atms.	10·75	10·93	11·12	11·05	11·31	10·55	11·06
Absolute Steam Pressure before the Nozzle. Atms.	2·70	9·72	10·10	10·90	11·25	10·20	10·99
Steam Temperature before the Nozzle. Deg. Cent.	129·3	177·6	179·2	182·5	184·1	179·0	248·3
Absolute Pressure in the first stage. Atms.	0·342	1·583	1·693	1·765	1·890	2·040	1·794
Absolute Pressure in the second stage. Atms.	0·145	0·103	0·095	0·097	1·099	0·101	0·102
Revolutions per minute	3510	3552	3541	3532	3550	3549	3542
Brake Horse-power	...	12·72	27·34	38·40	51·50	60·20	50·86
Steam Consumption. Kgs. per hour	139·5	214·3	336·2	434·5	548·0	690·0	468·5
Steam Consumption. Kgs. per B.H.P. hour	...	16·82	12·30	11·30	10·60	11·45	9·24
Thermodynamic Efficiency = $\frac{\text{Consumption of Ideal Machine}}{\text{Consumption of Actual Machine}}$ per cent.	...	22·1	29·3	32·9	35·0	32·4	38·8

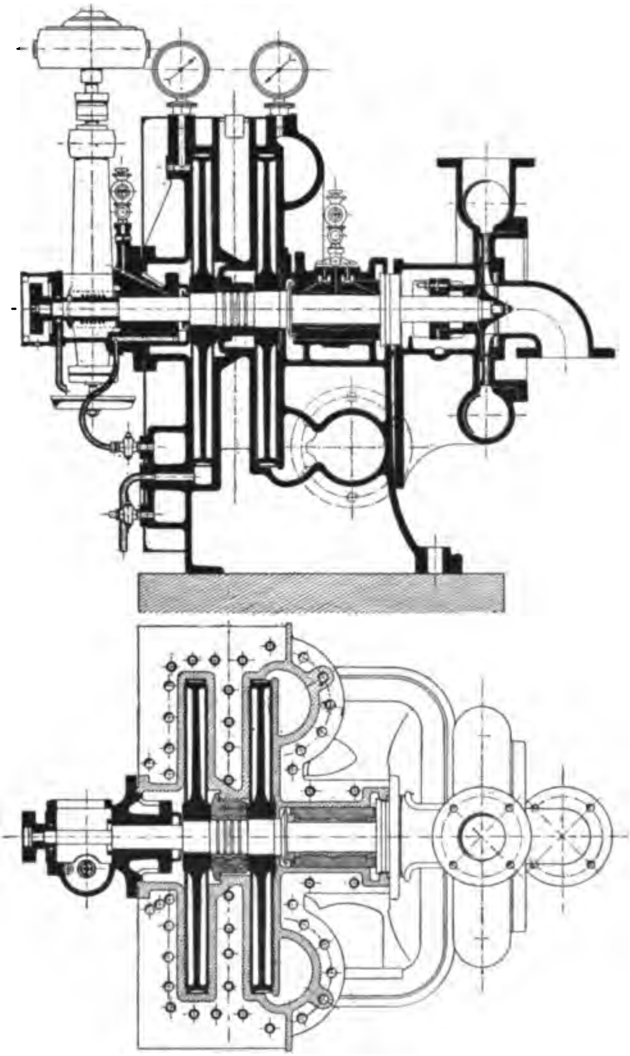


FIG. 232.—Sections through 50 Horse-power 'Union' Steam Turbine. $\frac{1}{10}$ full size.

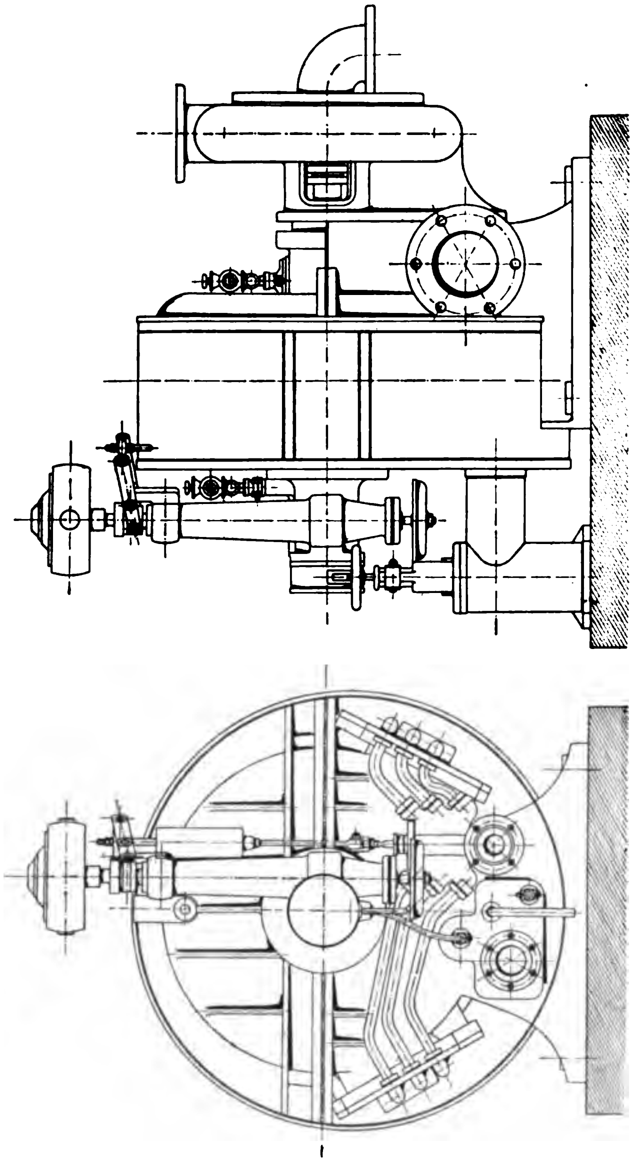


FIG. 233.—50 Horse-power 'Union' Steam Turbine, 3500 R.p.m. $\frac{1}{10}$ full size.

facturers of the Union turbine, for kindly placing at their disposal most of the illustrations in this chapter. Other illustrations and details have been taken, by permission, from the *Zeitschrift des*

FIG. 234.—Photograph of 50 Horse-power Union Steam Turbine.

Vereines Deutscher Ingenieure for June 24th, 1905, "Dampfturbinen," p. 1046, and the *Zeitschrift für das Gesamte Turbinenwesen* for June 15th, 1905, "Die Union-Dampfturbine," p. 209.

CHAPTER XIII

A RECAPITULATION OF THE PROPERTIES OF STEAM

THE properties of steam can be conveniently studied in connection with Table XCIII. or XCIV. In column I. are given the absolute pressures in kilograms per square centimetre, ranging from 0·05 kilograms per square centimetre up to 18 kilograms per square centimetre. A certain temperature corresponds to each pressure at which water evaporates. This temperature is given in column 2 in degrees of the Centigrade thermometer scale, and in column 3 in degrees Centigrade above absolute zero ($-273°$ C.). Table XCIV. gives the corresponding Fahrenheit temperatures.

In all practical applications of steam tables and of steam curves the chief interest attaches to the energy possessed by the steam under various conditions of pressure and temperature, which can theoretically be converted into work.

Heat in Liquid.—Before evaporating at any fixed pressure, water must first be heated to the corresponding temperature (t) given in column 2, and each kilogram of water at 0° Cent. requires for that purpose approximately one kilogram-calorie for each degree of temperature above 0° C., *i.e.* approximately as many kilogram-calories as the number expressing temperature, given in column 2. This amount of heat, called the "heat in the liquid," or "sensible heat" (S), is given with fair accuracy by the formula

$$S = t_C + 0{\cdot}00002\, t_C^2 + 0{\cdot}0000003\, t_C^3 \text{ [metric units, Table XCIII.]}$$

$$S = 32 - t_F + 0{\cdot}000000103\, (t_F - 32)^3 \text{ [English units, Table XCIV.]}$$

—the subscripts C and F indicating the Centigrade and Fahrenheit thermometer scales respectively.

Latent Heat.—To effect evaporation additional energy is

TABLE XCIII.—(METRIC UNITS)—PROPERTIES OF STEAM.

Absolute Pressure in Kgs. per Sq. Cm.	Temperature of Saturated Steam. °C.		CONSULT THESE COLUMNS TO OBTAIN THE ENERGY IN KG. C. CONTAINED IN ONE KG. OF STEAM.								
			Component Parts, *i.e.* Increase in Energy when Heating one Kg. of					Total Energy, *i.e.* Energy contained in one Kg. of			
	Temperature in Centigrade Scale (t).	Absolute Temperature (=273+t).	Water at 0° C. to Water at t° C. (Heat in Liquid).	Water at t° C. to Saturated Steam at t° C.	Saturated Steam to Steam at 50° C. Superheat.	Steam from 50° C. Superheat to 100° C. Superheat.	Steam from 100° C. Superheat to 150° C. Superheat.	Saturated Steam.	Steam at 50° C. Superheat.	Steam at 100° C. Superheat.	Steam at 150° C. Superheat.
Col. (1)	Col. (2)	Col. (3)	Col. (4)	Col. (5)	Col. (6)	Col. (7)	Col. (8)	Col. (9)	Col. 10)	Col. 11)	Col. (12)
·05	32	305	32	549	18·2	18·2	18·2	581	599	617	635
·06	36	309	36	546	18·2	18·2	18·2	582	600	618	636
·07	39	312	39	544	18·2	18·2	18·2	583	601	619	637
·08	42	315	42	542	18·2	18·2	18·2	584	602	620	638
·09	44	317	44	540	18·3	18·3	18·3	584	602	620	639
0·1	46	319	46	539	18·3	18·3	18·3	585	603	621	639
0·12	49	322	49	537	18·4	18·3	18·3	586	604	622	640
0·14	52	325	52	534	18·4	18·3	18·3	586	604	622	640
0·16	55	328	55	532	18·5	18·4	18·4	587	605	623	641
0·18	58	331	58	530	18·5	18·4	18·4	588	606	624	642
0·2	60	333	60	528	18·6	18·5	18·5	588	607	625	643
0·22	63	336	63	526	18·6	18·5	18·5	589	607	625	643
0·24	65	338	65	524	18·7	18·6	18·5	589	608	626	644
0·26	66	339	66	523	18·8	18·6	18·6	589	608	627	645
0·28	67	340	67	522	18·8	18·7	18·6	589	608	627	646
0·3	69	342	69	521	18·9	18·7	18·6	590	609	628	647
0·35	72	345	72	519	18·9	18·8	18·7	591	610	629	648
0·4	75	348	75	516	19·0	18·8	18·7	591	610	629	648
0·45	78	351	78	514	19·1	18·9	18·8	592	611	630	649
0·5	81	354	81	511	19·1	19·0	18·8	592	611	630	649
0·6	86	359	86	508	19·2	19·0	18·9	593	612	631	650
0·7	90	363	90	505	19·2	19·1	18·9	594	613	632	651
0·8	93	366	93	502	19·3	19·2	19·0	595	614	633	652
0·9	96	369	96	499	19·4	19·2	19·0	596	615	634	653
1·0	99	372	99	497	19·5	19·3	19·1	596	616	635	654
1·2	104	377	104	493	19·6	19·4	19·2	597	617	636	655
1·4	109	382	109	489	19·7	19·5	19·2	598	618	637	656
1·6	113	386	113	486	19·9	19·6	19·3	599	619	638	657
1·8	116	389	117	483	20·1	19·7	19·4	600	620	640	659
2·0	120	393	121	481	20·3	19·8	19·5	601	621	641	660
2·2	123	396	124	478	20·5	19·9	19·6	602	622	642	662
2·4	125	398	126	476	20·7	20·0	19·6	602	623	643	663
2·6	128	401	129	474	20·9	20·1	19·7	603	624	644	664
2·8	131	404	132	472	21·1	20·2	19·8	604	625	645	665
3·0	133	406	134	470	21·3	20·3	19·9	604	625	645	665
3·2	135	408	136	469	21·5	20·4	20·0	605	626	646	666
3·4	137	410	138	467	21·7	20·6	20·1	605	627	647	667
3·6	139	412	140	465	21·9	20·7	20·2	605	627	648	668
3·8	141	414	142	464	22·1	20·9	20·3	606	628	649	669
4·0	143	416	144	462	22·3	21·1	20·4	606	629	650	670
4·5	147	420	148	459	22·5	21·3	20·5	607	630	651	671
5·0	151	424	152	456	22·7	21·5	20·7	608	631	652	673
5·5	155	428	156	453	22·9	21·8	20·9	609	632	654	675
6·0	158	431	160	450	23·3	22·1	21·1	610	633	655	676
6·5	161	434	163	448	23·7	22·4	21·3	611	635	657	678
7·0	164	437	166	446	24·1	22·7	21·5	612	636	659	680
7·5	167	440	169	443	24·5	23·0	21·7	612	637	660	682
8·0	169	442	171	441	24·9	23·3	21·9	613	638	661	683
9·0	174	447	176	437	25·3	23·6	22·1	614	639	662	684
10·0	179	452	181	434	25·7	23·9	22·3	615	641	665	686
11·0	183	456	186	431	26·1	24·2	22·5	616	642	666	688
12·0	187	460	190	428	26·5	24·5	22·7	617	643	667	690
13·0	191	464	194	425	26·9	24·8	23·0	618	645	670	692
14·0	194	467	197	422	27·3	25·1	23·3	619	646	671	694
15·0	197	470	200	419	27·7	25·5	23·5	619	647	672	696
16·0	200	473	204	417	28·1	25·9	23·8	620	648	674	698
17·0	203	476	207	415	28·5	26·3	24·1	621	649	675	699
18·0	206	479	210	412	28·9	26·7	24·5	622	651	677	701

N.B.—t denotes the temperature of saturated steam.

TABLE XCIII.—(METRIC UNITS)—*continued.*

Absolute Pressure in Kgs. per Sq. Cm.	CONSULT THESE COLUMNS TO OBTAIN THE ENERGY IN KG. C. NECESSARY TO RAISE ONE KG. OF STEAM AT CONSTANT PRESSURE.								
	Component Parts, *i.e.* Heat required to raise one Kg. of					Total Energy, *i.e.* Heat required to raise Steam from one Kg. of Water at 0° C.			
	Water at 0° C. to Water at t° C. (Heat in Liquid).	Water at t° C. to Saturated Steam at t° C.	Saturated Steam to Steam at 50° C. Superheat.	Steam from 50° C. Superheat to 100° C. Superheat.	Steam from 100° C. Superheat to 150° C. Superheat.	Saturated Steam.	Steam at 50° C. Superheat.	Steam at 100° C. Superheat.	Steam at 150° C. Superheat.
Col. (1)	Col. (13)	Col. (14)	Col. (15)	Col. (16)	Col. (17)	Col. (18)	Col. (19)	Col. (20)	Col. (21)
·05	32	584	23·7	23·7	23·7	616	640	664	688
·06	36	581	23·7	23·7	23·7	617	641	665	689
·07	39	579	23·7	23·7	23·7	618	642	666	690
·08	42	577	23·7	23·7	23·7	619	643	667	691
·09	44	576	23·8	23·8	23·8	620	644	668	692
0·1	46	575	23·8	23·8	23·8	620	644	668	692
0·12	49	572	23·9	23·8	23·8	621	645	669	693
0·14	52	570	23·9	23·8	23·8	622	646	670	694
0·16	55	568	24·0	23·9	23·9	623	647	671	695
0·18	58	566	24·0	23·9	23·9	624	648	672	696
0·2	60	565	24·1	24·0	24·0	624	648	672	696
0·22	63	563	24·1	24·0	24·0	625	649	673	697
0·24	65	561	24·2	24·1	24·0	625	649	673	697
0·26	66	560	24·3	24·1	24·1	626	650	674	698
0·28	67	559	24·3	24·2	24·1	626	650	674	698
0·3	69	558	24·4	24·2	24·1	627	651	675	699
0·35	72	556	24·4	24·3	24·2	628	652	676	700
0·4	75	554	24·5	24·3	24·2	629	653	677	702
0·45	78	552	24·6	24·4	24·3	630	654	678	702
0·5	81	550	24·6	24·5	24·3	631	656	680	704
0·6	86	547	24·7	24·5	24·4	633	658	683	707
0·7	90	544	24·7	24·6	24·4	634	659	684	708
0·8	93	541	24·8	24·7	24·5	635	660	685	709
0·9	96	539	24·9	24·7	24·5	636	661	686	710
1·0	99	537	25·0	24·8	24·6	637	662	687	711
1·2	104	534	25·1	24·9	24·7	638	663	688	713
1·4	109	530	25·2	25·0	24·7	640	665	690	715
1·6	113	527	25·4	25·1	24·8	641	666	691	716
1·8	117	525	25·6	25·2	24·9	642	667	692	717
2·0	121	523	25·8	25·3	25·0	643	669	694	719
2·2	124	520	26·0	25·4	25·1	644	670	695	720
2·4	125	518	26·2	25·5	25·1	645	671	696	721
2·6	129	517	26·4	25·6	25·2	646	672	697	722
2·8	132	515	26·6	25·7	25·3	646	673	699	724
3·0	134	513	26·8	25·8	25·4	647	674	700	725
3·2	136	512	27·0	25·9	25·5	648	675	701	726
3·4	138	510	27·2	26·1	25·6	648	675	701	727
3·6	140	509	27·4	26·2	25·7	649	676	702	728
3·8	142	507	27·6	26·4	25·8	649	677	703	729
4·0	144	506	27·8	26·6	25·9	650	678	704	730
4·5	148	503	28·0	26·8	26·0	651	679	706	732
5·0	152	500	28·2	27·0	26·2	652	680	707	733
5·5	156	497	28·4	27·3	26·4	653	681	708	734
6·0	160	495	28·8	27·6	26·6	654	683	711	737
6·5	163	493	29·2	27·9	26·8	655	684	712	739
7·0	166	491	29·6	28·2	27·0	656	686	714	741
7·5	169	489	30·0	28·5	27·2	657	687	715	742
8·0	171	487	30·4	28·8	27·4	658	688	716	743
9·0	176	483	30·8	29·1	27·6	660	691	720	747
10·0	181	480	31·2	29·4	27·8	661	692	721	749
11·0	186	477	31·6	29·7	28·0	662	693	723	751
12·0	190	474	32·0	30·0	28·2	663	695	725	753
13·0	194	471	32·4	30·3	28·5	665	697	727	755
14·0	197	469	32·8	30·6	28·8	666	699	729	758
15·0	200	466	33·2	31·0	29·0	667	700	731	760
16·0	204	464	33·6	31·4	29·3	668	701	732	761
17·0	207	462	34·0	31·8	29·6	668	702	734	763
18·0	210	460	34·4	32·2	30·0	669	703	735	765

N.B.—*t* denotes the temperature of saturated steam.

TABLE XCIII.—(METRIC UNITS)—*continued.*

Absolute Pressure in Kgs. per Sq. Cm.	Specific Volume in Cubic Metres per Kg.				Specific Weight in Kgs. per Cubic Metre.			
	Saturated Steam.	Steam at 50° C. Superheat.	Steam at 100° C. Superheat.	Steam at 150° C. Superheat.	Saturated Steam.	Steam at 50° C. Superheat.	Steam at 100° C. Superheat.	Steam at 150° C. Superheat.
Col. (1)	Col. (22)	Col. (23)	Col. (24)	Col. (25)	Col. (26)	Col. (27)	Col. (28)	Col. (29)
·05	28·	33·4	38·2	42·8	·0357	·03	·0262	·0234
·06	24·1	28·1	32·1	36·2	·0415	·0356	·0312	·0777
·07	20·8	24·3	27·7	31·6	·048	·0412	·0362	·0317
·08	18·0	21·4	24·5	27·4	·055	·0468	·0409	·0365
·09	16·7	19·2	21·8	24·5	·060	·0521	·046	·0408
0·1	15·0	17·3	19·70	22·0	·066	·0576	·0508	·0455
0·12	12·3	14·6	16·5	18·5	·0813	·0686	·0606	·0542
0·14	10·8	12·6	14·3	15·9	·0925	·0795	·070	·063
0·16	9·5	11·1	12·6	14·0	·105	·0902	·0795	·0714
0·18	8·5	9·94	11·3	12·3	·117	·1008	·0885	·0814
0·2	7·78	8·97	10·2	11·3	·130	·1115	·0985	·0885
0·22	7·15	8·25	9·33	10·4	·140	·1215	·107	·096
0·24	6·63	7·60	8·58	9·58	·151	·131	·117	·1050
0·26	6·10	7·02	7·94	8·86	·164	·1425	·126	·113
0·28	5·70	6·53	7·40	8·23	·176	·153	·135	·122
0·3	5·30	6·11	6·93	7·70	·187	·163	·1445	·130
0·35	4·60	5·28	5·96	6·64	·218	·1895	·168	·151
0·4	4·04	4·63	5·26	5·85	·246	·216	·190	·171
0·45	3·65	4·17	4·70	5·25	·274	·240	·213	·191
0·5	3·27	3·78	4·26	4·74	·306	·264	·235	·212
0·6	2·75	3·18	3·58	3·96	·364	·314	·279	·253
0·7	2·38	2·75	3·10	3·44	·420	·364	·322	·291
0·8	2·10	2·43	2·72	3·02	·476	·410	·367	·332
0·9	1·88	2·17	2·44	2·70	·532	·459	·409	·370
1·0	1·70	1·96	2·21	2·44	·587	·509	·453	·409
1·2	1·43	1·66	1·85	2·05	·697	·603	·538	·489
1·4	1·24	1·434	1·60	1·77	·806	·696	·625	·565
1·6	1·09	1·27	1·41	1·56	·916	·790	·708	·642
1·8	·978	1·180	1·26	1·400	1·02	·886	·795	·714
2·0	·886	·102	1·14	1·26	1·13	·976	·875	·794
2·2	·810	·939	1·04	1·15	1·24	1·065	·956	·868
2·4	·740	·864	·962	1·06	1·34	1·155	1·04	·945
2·6	·692	·800	·890	·98	1·45	1·25	1·125	1·02
2·8	·645	·746	·830	·918	1·55	1·34	1·205	1·09
3·0	·605	·700	·780	·858	1·66	1·43	1·28	1·165
3·2	·569	·660	·732	·806	1·76	1·515	1·37	1·24
3·4	·538	·621	·692	·760	1·86	1·615	1·45	1·316
3·6	·510	·588	·664	·720	1·96	1·70	1·51	1·39
3·8	·484	·558	·620	·684	2·07	1·79	1·615	1·46
4·0	·461	·532	·592	·672	2·17	1·885	1·69	1·49
4·5	·413	·474	·528	·580	2·42	2·11	1·90	1·725
5·0	·374	·431	·474	·524	2·67	2·32	2·11	1·91
5·5	·342	·394	·437	·480	2·92	2·54	2·29	2·085
6·0	·315	·360	·401	·441	3·16	2·78	2·50	2·270
6·5	·292	·336	·370	·407	3·41	2·98	2·70	2·45
7·0	·273	·312	·345	·380	3·66	3·20	2·89	2·63
7·5	·255	·292	·323	·354	3·90	3·43	3·10	2·88
8·0	·240	·283	·303	·332	4·14	3·54	3·30	3·02
9·0	·215	·244	·270	·296	4·63	4·10	3·71	3·38
10·0	·195	·220	·243	·267	5·11	4·55	4·18	3·75
11·0	·178	·200	·222	·243	5·62	5·00	4·51	4·12
12·0	·164	·184	·204	·223	6·09	5·44	4·91	4·48
13·0	·153	·170	·188	·206	6·53	5·90	5·33	4·76
14·0	·142	·157	·175	·191	7·01	6·38	5·72	5·23
15·0	·133	·147	·163	·179	7·48	6·80	6·14	5·58
16·0	·125	·137	·152	·167	7·94	7·28	6·58	5·98
17·0	·118	·129	·143	·157	8·42	7·75	7·00	6·36
18·0	·112	·122	·135	·148	8·86	8·20	7·41	6·76

TABLE XCIV.—(ENGLISH UNITS).

Absolute Pressure. Lbs. per Sq. In.	Temperature of Saturated Steam. °F. On Fahrenheit Scale.	Temperature of Saturated Steam. °F. Absolute 459·4+t.	Consult these Columns to obtain the Energy in B.Th.U. contained in one Lb. of Steam. Component Parts, *i.e.* Increase in Energy when heating one Lb. of Water at 32° F. to Water at t° F. "Heat in Liquid."	Water at t° F. to Saturated Steam at t° F.	Steam at Saturation to Steam at 100° F. Superheat.	Steam at 100° F. Superheat to Steam at 200° F. Superheat.	Steam at 200° F. Superheat to Steam at 300° F. Superheat.	Total Energy, *i.e.*, Energy contained in 1 Lb. of Steam at Saturation.	100° F. Superheat.	200° F. Superheat.	300° F. Superheat.
Col. (1)	Col. (2)	Col. (3)	Col. (4)	Col. (5)	Col. (6)	Col. (7)	Col. (8)	Col. (9)	Col. (10)	Col. (11)	Col. (12)
0·50	79·8	539	47·8	999	36·8	36·7	36·7	1047	1084	1120	1157
0 75	91·5	551	59·6	990	36·9	,,	,,	1049	1086	1123	1159
1·00	102	561	70·0	981	,,	,,	,,	1051	1088	1125	1162
1·25	109	569	77·6	975	37·0	,,	,,	1053	1090	1127	1163
1·50	116	575	83·7	970	,,	36·8	,,	1054	1091	1128	1165
1·75	121	581	89 5	966	,,	,,	,,	1056	1093	1129	1166
2·00	126	586	94·4	962	37·1	,,	,,	1057	1094	1130	1167
2·25	131	590	98·7	959	,,	,,	,,	1058	1095	1131	1168
2·50	135	594	102·7	956	37·2	,,	,,	,,	1096	1132	1169
2·75	138	598	106·3	953	,,	,,	,,	1059	,,	1133	1170
3·00	142	601	109·8	950	37·3	,,	,,	1060	1097	1134	1171
3·5	148	607	115·8	945	,,	36·9	,,	1061	1098	1135	1173
4·0	153	613	121·3	941	37·4	,,	,,	1062	1100	1137	,,
4·5	158	617	126·1	937	37·5	,,	,,	1063	1101	1138	1174
5	162	622	130·6	934	37·6	,,	,,	1064	1102	1139	1175
6	170	630	138·4	928	37·7	37·0	,,	1066	1104	1141	1177
7	177	636	145·2	922	37·9	,,	,,	1067	1105	1142	1179
8	183	642	151·2	917	38·0	37·1	,,	1069	1107	1144	1180
9	188	648	156·7	913	38·1	,,	,,	1070	1108	1145	1182
10	193	653	161·7	909	38·2	37·2	,,	1071	1109	1146	1183
12	202	661	170·5	902	38·5	37·3	36·8	1073	1111	1149	1185
14	210	669	178·1	896	38·7	,,	,,	1075	1113	1151	1187
16	216	676	184·9	891	38·9	37·4	,,	1076	1115	1152	1189
18	222	682	191·1	886	39·2	37·5	,,	1077	1117	1154	1190
20	228	687	196·7	882	39·4	37·6	,,	1079	1118	1156	1192
22	233	692	202	878	39·6	37·7	36·9	1080	1119	1157	1194
24	238	697	207	874	39·8	37·8	,,	1081	1121	1158	1195
26	242	701	211	871	40·0	,,	,,	1082	1122	1160	1196
28	246	706	215	867	40·2	37·9	,,	1083	1123	1161	1198
30	250	710	219	864	40·4	38·0	37·0	1084	1124	1162	1199
35	259	719	228	857	40·8	38·2	,,	1086	1126	1165	1202
40	267	727	236	851	41·3	38·4	37·1	1087	1129	1167	1204
45	274	734	244	845	41·7	38·5	,,	1089	1131	1169	1206
50	281	740	250	841	42·1	38·7	37·2	1090	1133	1171	1208
55	287	746	257	835	42·5	38·9	37·3	1092	1134	1173	1211
60	293	752	262	831	43·0	39·0	,,	1093	1136	1175	1212
65	298	757	268	827	43·3	39·2	37·4	1094	1138	1177	1214
70	303	762	273	823	43·7	39·4	,,	1095	1139	1179	1216
75	307	767	277	819	44·1	39·5	37·5	1097	1141	1180	1218
80	312	771	282	816	44·4	39·7	,,	1098	1142	1182	1219
85	316	775	286	812	44·8	39·9	37·6	1099	1143	1183	1221
90	320	779	290	809	45·1	40·0	37·7	,,	1145	1185	1222
95	324	783	294	806	45·5	40·2	,,	1100	1146	1186	1224
100	328	787	298	803	45·8	40·3	37·8	1101	1147	1187	1225
110	335	794	305	798	46·4	40·6	37·9	1103	1149	1190	1228
120	341	800	312	743	47·1	40·9	38·0	1104	1152	1192	1230
130	347	807	318	788	47·7	41·2	38·1	1106	1154	1195	1233
140	353	812	324	783	48·3	41·4	38·3	1107	1155	1197	1235
150	358	818	330	779	48·9	41·8	38·4	1109	1157	1199	1238
160	363	823	335	775	49·5	42·0	38·5	1110	1159	1201	1240
170	368	828	340	771	50·0	42·3	38·6	1111	1161	1203	1242
180	373	832	345	767	50·6	42·6	38·7	1112	1163	1205	1244
190	377	837	349	764	51·1	42·8	38·8	1113	1164	1207	1246
200	382	841	354	760	51·7	43·1	38·9	1114	1166	1209	1248
210	386	845	358	757	52·2	43·3	39·0	1115	1168	1211	1250
220	390	849	362	754	52·7	43·6	39·1	1116	1169	1213	1252
230	394	853	366	751	53·2	43·8	39·2	1117	1171	1214	1254
240	397	857	370	748	53·7	44·1	39·3	1118	1172	1216	1255
250	401	860	374	745	54·2	44·3	39·5	1119	1173	1218	1257
260	405	864	377	742	54·7	44·6	30·6	1120	1174	1219	1259
270	408	867	381	740	55·1	44·8	39·7	1121	1176	1221	1260
280	411	870	384	737	55·6	45·0	39·8	1122	1177	1222	1262
290	414	874	388	735	56·1	45·3	39·9	1122	1178	1224	1263
300	417	877	391	732	56·5	45·5	40·0	1123	1179	1225	1265

TABLE XCIV.—(ENGLISH UNITS)—*continued.*

Absolute Pressure. Lbs. per Sq. In.	Consult these Columns to obtain the Energy in B.Th.U. necessary to raise one Lb. of Steam at Constant Pressure.								
	Compound Parts, *i.e.* Heat required to raise 1 Lb. of					Total Energy, *i.e.* Heat required to raise 1 Lb. of Water at 32° F. to Steam at			
	Water at		Steam at						
	32° F. to Water at t° F. "Heat in Liquid."	t° F. to Saturated Steam at t° F.	Saturation to Steam at 100° F. Superheat.	100° F. Superheat to Steam at 200° F. Superheat.	200° F. Superheat to Steam at 300° F. Superheat.	Saturation.	100° F. Superheat.	200° F. Superheat.	300° F. Superheat.
Col. (1)	Col. (13)	Col. (14)	Col. (15)	Col. (16)	Col. (17)	Col. (18)	Col. (19)	Col. (20)	Col. (21)
0·50	47·8	1059	47·8	47·7	47·7	1106	1154	1202	1250
0·75	59·6	1050	47·9	,,	,,	1110	1158	1206	1253
1·00	70·0	1043	47·9	77·8	,,	1113	1161	1209	1257
1·25	77·6	1038	48·0	,,	,,	1115	1163	1211	1259
1·50	83·7	1034	,,	,,	,,	1117	1165	1213	1261
1·75	89·5	1030	48·1	,,	,,	1119	1167	1215	1263
2·00	94·4	1026	,,	,,	,,	1121	1169	1216	1264
2·25	98·7	1023	48·2	,,	,,	1122	1170	1218	1266
2·50	102·7	1020	,,	,,	,,	1123	1171	1219	1267
2·75	106·3	1018	48·3	47·9	,,	1124	1172	1220	1268
3·00	109·8	1015	,,	,,	,,	1125	1173	1221	1269
3·50	115·8	1011	48·4	,,	,,	1127	1175	1223	1271
4·0	121·8	1007	48·5	,,	,,	1129	1177	1225	1273
4·5	126·1	1004	,,	,,	,,	1130	1179	1227	1274
5	130·6	1001	48·6	48·0	,,	1132	1180	1228	1276
6	138·4	995	48·7	,,	,,	1134	1183	1231	1278
7	145·2	991	48·9	48·1	,,	1136	1185	1233	1281
8	151·2	987	49·0	,,	47·8	1138	1187	1235	1283
9	156·7	983	49·1	48·2	,,	1139	1189	1237	1284
10	161·7	979	49·3	,,	,,	1141	1190	1238	1286
12	170·5	973	49·5	48·3	,,	1144	1193	1241	1289
14	178·1	968	49·8	48·4	,,	1146	1196	1244	1292
16	184·9	963	50·0	48·5	,,	1148	1198	1246	1294
18	191·1	959	50·2	,,	48·9	1150	1200	1249	1296
20	196·7	955	50·4	48·6	,,	1152	1202	1251	1298
22	202	951	50·6	48·7	,,	1153	1204	1252	1300
24	207	948	50·8	48·8	,,	1155	1205	1254	1302
26	211	945	51·0	48·9	48·0	1156	1207	1256	1304
28	215	942	51·2	,,	,,	1157	1208	1257	1305
30	219	939	51·4	49·0	,,	1158	1210	1259	1307
35	228	933	51·9	49·2	,,	1161	1213	1262	1310
40	236	927	52·3	49·4	48·1	1163	1216	1265	1313
45	244	922	52·8	49·6	48·2	1166	1218	1268	1316
50	250	917	53·2	49·7	48·2	1168	1221	1271	1319
55	257	913	53·6	49·9	48·3	1170	1223	1273	1321
60	262	909	54·0	50·1	48·4	1171	1225	1275	1324
65	268	905	54·4	50·3	,,	1173	1227	1277	1326
70	273	902	54·7	50·4	48·5	1174	1229	1279	1328
75	277	898	55·1	50·6	,,	1176	1231	1281	1330
80	282	895	55·5	50·7	48·6	1177	1233	1283	1332
85	286	892	55·8	50·9	48·6	1178	1234	1285	1334
90	290	889	56·2	51·1	48·7	1180	1236	1287	1336
95	294	886	56·5	51·2	48·8	1181	1237	1289	1337
100	298	884	56·8	51·4	48·8	1182	1239	1290	1339
110	305	879	57·5	51·7	48·9	1184	1242	1293	1342
120	312	874	58·1	52·0	49·0	1186	1244	1296	1345
130	318	870	58·7	52·2	49·2	1188	1247	1299	1348
140	324	866	59·3	52·5	49·3	1190	1249	1301	1351
150	330	862	59·9	52·8	49·4	1191	1251	1304	1353
160	335	858	60·5	53·1	49·5	1193	1253	1306	1356
170	340	854	61·1	53·3	49·6	1194	1255	1309	1342
180	345	851	61·6	53·6	49·7	1196	1257	1311	1361
190	349	848	62·2	53·9	49·8	1197	1259	1313	1363
200	354	845	62·7	54·1	49·9	1198	1261	1315	1365
210	358	842	63·2	54·4	50·1	1200	1263	1317	1367
220	362	839	63·7	54·6	50·2	1201	1265	1319	1369
230	366	836	64·2	54·9	50·3	1202	1266	1321	1371
240	370	833	64·7	55·1	50·4	1203	1268	1323	1373
250	374	830	65·2	55·4	50·5	1204	1270	1325	1375
260	377	828	65·7	55·6	50·6	1205	1271	1327	1377
270	381	825	66·2	55·8	50·7	1206	1273	1328	1379
280	384	823	66·6	56·1	50·8	1207	1274	1330	1381
290	388	821	67·1	56·3	50·9	1208	1275	1332	1383
300	391	818	67·6	56·5	51·0	1209	1277	1333	1384

TABLE XCIV.—ENGLISH UNITS—*continued.*

Absolute Pressure. Lbs. per Sq. In.	Specific Volume. Cubic Feet per 1 Lb. of Steam at				Specific Weight. Lb. per Cubic Foot of Steam at			
	Saturation.	100° F. Superheat.	200° F. Superheat.	300° F. Superheat.	Saturation.	100° F. Superheat.	200° F. Superheat.	300° F. Superheat.
Col. (1)	Col. (22)	Col. (23)	Col. (24)	Col. (25)	Col. (26)	Col. (27)	Col. (28)	Col. (29)
0·50	633	762	881	1001	0·00158	0·00131	0·00114	0·00100
0·75	433	517	597	676	0·00231	0·00193	0·00167	0·00148
1·00	330	394	454	513	0·00303	0·00254	0·00220	0·00195
1·25	267	319	367	414	0·00374	0·00313	0·00272	0·00242
1·50	226	268	306	348	0·00443	0·00373	0·00325	0·00287
1·75	195	232	266	300	0·00513	0·00431	0·00376	0·00333
2·00	172	204	234·0	264	0·00581	0·00190	0·00427	0·00379
2·25	151	183	209	236	0·00664	0·00547	0·00478	0·00423
2·50	140	165	189	213 0	0·00717	0·00606	0·00529	0·00469
2·75	128	151	173	194·4	0·00784	0·00662	0·00578	0·00515
3·00	118	139	159·0	178·8	0·00850	0·00719	0·00629	0·00559
3·5	102	120	137·2	154·3	0·00983	0·00833	0·00730	0·00649
4·0	89·8	106·0	120·9	135·8	0·01114	0·00953	0·00827	0·00737
4·5	80·3	94·8	108·0	121·3	0·01245	0·01053	0·03926	0·00826
5	72 8	85·8	97·7	109·7	0·01374	0·01165	0·01023	0·00912
6	61·3	72·2	82·2	92·1	0·01630	0·01384	0·01217	0·01086
7	53·0	62·5	71·0	79·5	0·01885	0·01603	0·01408	0·01258
8	46·8	55·1	62·5	70·0	0·0214	0·01816	0·01600	0·01429
9	41·9	49·3	55·9	62·5	0·0239	0·0203	0·0179	0·01600
10	37·9	44·6	50·6	56·5	0·0263	0·0224	0·0197	0·01770
12	32·0	37·6	42·5	47·5	0·0313	0·0266	0·0235	0·0210
14	27·7	32·5	36·8	41·0	0·0361	0·0308	0·0272	0·0244
16	24·4	28·7	32·4	36·1	0·0410	0·0349	0·0309	0·0277
18	21·8	25·6	29·0	32·3	0·0458	0 0390	0·0345	0·0310
20	19·79	23·2	26·2	29·2	0·0505	0·0431	0·0382	0·0342
22	18·10	21·2	23·9	26·6	0·0553	0·0471	0·0418	0·0376
24	16·67	19·55	22·0	24·5	0·0600	0·0511	0·0465	0·0408
26	15·47	18·13	20·4	22·7	0·0646	0·0552	0·0490	0·0440
28	14·43	16·90	19·03	21·2	0·0693	0·0592	0·0526	0·0473
30	13·52	15·84	17·82	19·8	0·0739	0·0632	0·0562	0·0505
35	11·70	13·69	15·39	17·10	0·0855	0·0730	0·0649	0·0585
40	10·32	12·06	13·56	15·05	0·0969	0·0826	0·0735	0·0667
45	9·24	10·79	12·12	13·44	0·1082	0·0926	0·0826	0·0746
50	8·37	9·77	10·96	12·15	0·1195	0·1024	0·0909	0·0820
55	7·65	8·92	10·00	11·09	0·1307	0·1121	0·100[illegible]	0·0901
60	7·05	8·21	9·20	10·20	0·1418	0·1218	0·1087	0·0980
65	6·54	7·61	8·52	9·44	0·1529	0 1314	0·1174	0·1059
70	6·10	7·09	7·94	8·79	0·1639	0·1410	0·1259	0·1138
75	5·72	6·64	7·43	8·28	0·1749	0·1506	0·1346	0·1215
80	5·38	6·24	6·98	7·73	0·1858	0·1603	0·1433	0·1294
85	5·08	5·88	6·59	7·29	0·1967	0·1701	0·1517	0·1372
90	4·82	5·57	6·23	6·90	0·208	0·180	0·1605	0 1449
95	4·58	5·29	5·92	6·54	0·218	0·1890	0·1689	0·1529
100	4·36	5·03	5·63	6·23	0·229	0·1988	0·1776	0·1606
110	3·99	4·59	5·13	5·67	0·251	0·219	0·1949	0·1764
120	3·68	4·22	4·71	5·21	0·272	0·237	0·212	0·1919
130	3·41	3·90	4·36	4·82	0·293	0·256	0·229	0·207
140	3·18	3·63	4·05	4·48	0·314	0·275	0·248	0 223
150	2·98	3·39	3·79	4·19	0·335	0·295	0·264	0·239
160	2·86	3·18	3·56	3·93	0·356	0·314	0·281	0·254
170	2·65	3·00	3·35	3·70	0·377	0·333	0·299	0·270
180	2·51	2·83	3·17	3·50	0·398	0 353	0·315	0·286
190	2·39	2·68	3·00	3·31	0·419	0·373	0·333	0·302
200	2·28	2·55	2·85	3·15	0·439	0·392	0·350	0·317
210	2·17	2·43	2·71	3·00	0·460	0·412	0·369	0·333
220	2·10	2·32	2·59	2·86	0·480	0·431	0·386	0·350
230	1·996	2·21	2·47	2·73	0·501	0·452	0·404	0·366
240	1·918	2·12	2·37	2·62	0·521	0·472	0 422	0·382
250	1·846	2·03	2·27	2·51	0·542	0·493	0·441	0·398
260	1·779	1·954	2·18	2·41	0·562	0·513	0·459	0·415
270	1·717	1·880	2·10	2·32	0·582	0·532	0·476	0·431
280	1·659	1·810	2·02	2·24	0·603	0·553	0·495	0·446
290	1·606	1·746	1·951	2·16	0·623	0·571	0·513	0·463
300	1·555	1·685	1·884	2·08	0·043	0·592	0·532	0·481

required, called the "latent heat" (L). This is made up of two distinct components: first, that part required for evaporation (internal latent heat, L_i); second, that part required to overcome the mechanical work of expanding during evaporation against pressure, from the volume of water up to the volume of saturated steam (external latent heat, L_e).

The latter component amounts to only from 6 per cent. to 10 per cent of the total, but nevertheless it is of importance to carefully distinguish between the energy that is required in order to **obtain** a kilogram of steam at a given pressure, and the slightly less amount of energy **existing in** a kilogram of steam **at** that pressure. For this purpose we have in Tables XCIII. and XCIV. given two distinct groups of columns. Columns 4 to 12, Table XCIII., show the energy existing in one kilogram of steam in excess of that existing in one kilogram of water at 0° Cent., and columns 13 to 21 show the energy necessary to produce one kilogram of steam from one kilogram of water at 0° Cent. in kilogram degree calories.

Table XCIV. gives in columns 4 to 12 the energy existing in one pound of steam in excess of that in one pound of water at 32° F., and columns 13 to 21 show the energy necessary to produce one pound of steam from water at 32° F., all in British thermal units.

Let us first consider the columns giving the energy existing in a kilogram (or a pound) of steam. In column 4 the heat in the water just prior to vaporisation is given in terms of the kilogram-degree calories per kilogram,—Table XCIII. (in B.Th.U. in Table XCIV.). This differs at the higher temperatures by about 2 per cent. from the temperature of water in degrees Centigrade above 0° of that scale, and at lower temperatures by a considerably smaller percentage.

The whole amount of the latent heat, $L = L_i + L_e$, is given in column 14.

Internal Latent Heat.—The large additional amount of energy L_i imparted to the steam during vaporisation is given in column 5. It may be calculated by Zeuner's approximate formula,

$$L_i = 575{\cdot}4 - 0{\cdot}791\ t_C \text{ [metric units]}.$$

$$L_i = 1062 - 0{\cdot}79\ t_F \text{ [English units]}.$$

Steam and Water.—Let us now consider the intermediate condition in which only a part of the water is evaporated. Suppose

that 90 per cent. of the total water is in the form of steam, the remaining 10 per cent. still being liquid. The steam may be said to have 10 per cent. of moisture, or to have a wetness factor $x=0{\cdot}1$. It is clear that in such a mixture the energy is equal to the heat in the liquid plus 0·9 of the heat of vaporisation of the whole quantity,

$$S+(1-x)\,L_i=S+0{\cdot}9\,L_i.$$

The Convertible Energy in Saturated Steam.—For column 9, the values in columns 4 and 5 have been added together, thus giving the energy existing in one kilogram of saturated steam. It can also be considered as the difference between the total heat, H, and the external latent heat, L_e:

$$S+L_i=H-L_e.$$

$$H=S+L_i+L_e$$

Total Heat.—The total heat, H, in column 18, is the heat energy necessary to raise one unit of weight of water from freezing point up to saturated steam at a definite pressure and corresponding temperature. This is given by the approximate equations,

$$H=606{\cdot}5+0{\cdot}305\,t_C\ \text{[in kilogram calories]}.$$

$$H=1082+0{\cdot}305\,t_F\ \text{[in B.Th.U.]}.$$

Superheating.—As soon as the water has been completely evaporated, any additional supply of energy raises the temperature of the steam, assuming the pressure is kept constant. This brings us to what is known as the region of superheated steam. During the last few years the subject of superheated steam has come into great prominence, and its properties are of extreme interest. Of the additional energy required at constant pressure to raise the temperature of saturated steam, one part is necessary to provide the energy for overcoming the external pressure. This constitutes about 22 to 24 per cent. of the total additional energy. The remaining 78 to 76 per cent. serves to increase the available internal energy, *i.e.* to increase the temperature of the steam. The total additional energy per kilogram of superheated steam is equal to the specific heat at constant pressure, C_p, multiplied by $t'-t$, the difference in temperature of the superheated steam, t', and of the saturated steam, t, where C_p may be taken from Fig.

235. Three curves of Fig. 235 have been plotted by the formula proposed by Professor Callendar.[1] This formula is as follows:—

$$C_p = 0{\cdot}477 + 0{\cdot}093\left(\frac{273}{T}\right)^{\frac{10}{3}} p.$$

C_p = specific heat at the constant pressure, p.
p = absolute pressure in Kgs. per sq. cm.
$T = 273 + t$ = absolute temperature (Centigrade).

For Table XCIV., in English units, the following formula has been used:—

$$C_p = 0{\cdot}477 + 0{\cdot}00654\left(\frac{491{\cdot}4}{T_F}\right)^{\frac{10}{3}} p.$$

$T_F = 459{\cdot}4 + t_F$ = absolute Fahrenheit temperature.
t_F = temperature of the superheated steam on Fahrenheit scale.

The Curve C_4, Fig. 235, has been plotted (for comparison with C_2) by the formula proposed by Professor Linde (see footnote, page 352):—

$$C = \frac{1}{J} n \left\{ B + 3p(1 + ap)\frac{C}{T}\left(\frac{373}{T}\right)^3 \right\}$$

T is absolute Centigrade temperature; J is Joule's mechanical equivalent of heat $= 427$; p is pressure in kgs. per square *metre*; $n = 4{\cdot}232$; $B = 47{\cdot}10$; $a = 0{\cdot}000002$; $C = 0{\cdot}031$.

Professor Lorenz gave a simpler formula, which we have not used here, in *Zeitschr. d. Vereines deutsch. Ingenieure*, 1904, p. 700:

$$C_p = 0{\cdot}43 + 3{,}600{,}000\,\frac{p}{T^3} \text{ [in metric units].}$$

The total heat of superheated steam is

$$H' = H + C_p(t' - t).$$

The energy used in overcoming external pressure during superheating can be calculated in the same way as for saturated steam.

The external latent heat is calculated by the formula—

$$L_e = \frac{pu}{J}.$$

Here p is pressure; u is the increase in volume; and J is Joule's mechanical equivalent of heat.

[1] Professor Callendar proposed this formula in a paper read before the Royal Society (*Proc. Royal Society*, November 14th, 1900). The formula has also been used by Professor Dr. Mollier for his steam curves and tables, which have just been published in Berlin by Messrs Julius Springer. Dr Mollier's curves form a very desirable supplement to any work on steam turbines.

Specific Weights and Volumes.—The specific weight of saturated steam is given approximately by Zeuner by the following equation:—

$\gamma = ap^n$

γ = specific weight in kg. per cu. m., and p = the pressure.

If the pressure is given in kgs. per sq. cm.,

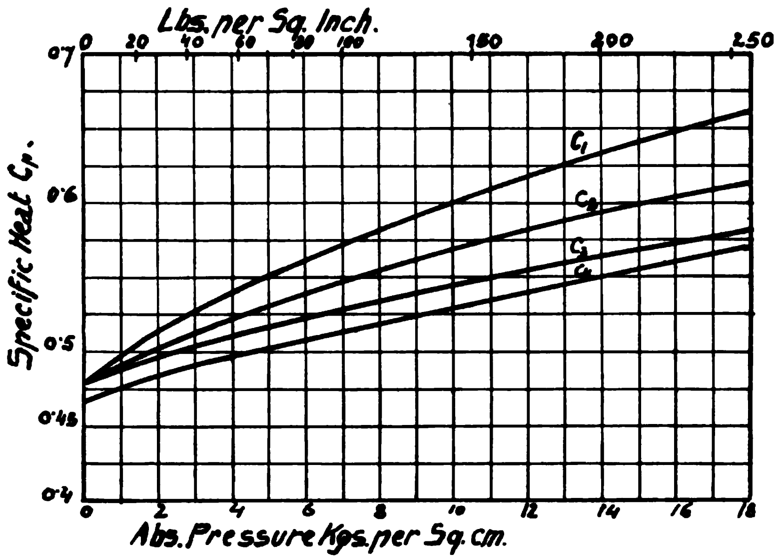


FIG. 235.—Specific Heat of Superheated Steam.

Curve C_1, Specific Heat at 50° C. Superheat (Callendar).
Curve C_2, Specific Heat at 100° C. Superheat (Callendar).
Curve C_3, Specific Heat at 150° C. Superheat (Callendar).
Curve C_4, Specific Heat at 100° C. Superheat (Linde).

$$a = 0{\cdot}5877;\ n = 0{\cdot}9393;\ \gamma = \text{kg. per cu. m.}$$

If the pressure is given in lbs. per sq. in.,

$$a = 0{\cdot}00303;\ n = 0{\cdot}9393;\ \gamma = \text{lbs. per cubic foot.}$$

The volume is then $v = \dfrac{1}{\gamma}$.

Specific Weights and Volumes of Superheated Steam.

The volume of superheated steam is for practical purposes correct enough if calculated by the formula given by Tumlirz.[1]

$pv = 0{\cdot}00471\ T - 0{\cdot}016\ p$. (in metric units).
v = volume in cu. m. per kg.
p = absolute pressure in kgs. per sq. cm.
T = absolute temperature on the Centigrade scale.

$pv = 0{\cdot}5963\ T - 0{\cdot}2563\ p$. (in English units).
v = volume in cu. feet per lb.
p = abs. pressure in lbs. per sq. in.
T = abs. temperature on the Fahrenheit scale.

We note also the formula given by Linde,[2] which shows the influence of the variable specific heat:—

$$pv = 0{\cdot}00471\ T - p\ (1 + 0{\cdot}000002\ p)\left[0{\cdot}031\left(\frac{373}{T}\right)^3 - 0{\cdot}0052\right]$$

when p, v, and T are in metric measures. In English measures Linde's formula is—

$$pv = 0{\cdot}5963\ T - 16{\cdot}02\ p(1 + 0{\cdot}000000141\ p)\left[0{\cdot}031\left(\frac{671{\cdot}4}{T}\right)^3 - 0{\cdot}0052\right].$$

On pages 344 and 347 are given the specific weights and the specific volumes of saturated and superheated steam, for all usual pressures and superheats up to 150° C and 300° F. It is interesting to note that the specific weight of saturated steam increases very nearly in proportion to the pressure.[3] Thus—

Abs. pressure = 0·1 Kg. per sq. cm.	Spec. weight = 0·067 Kg. per cub. metre.
Abs. pressure = 1·0 Kg. per sq. cm.	Spec. weight = 0·587 Kg. per cub. metre.
Abs. pressure = 10 Kg. per sq. cm.	Spec. weight = 5·11 Kg. per cub. metre.

The specific volume of wet steam can be taken as approximately—

$$\text{Specific volume} \approx (1 - x)v,$$

[1] Tumlirz, *Sitzungsberichte der k.k. Akad. d. Wissenschaften Math.-Naturw. Kl. Wien*, 1899, II*a*, page 1058.

[2] R. Linde, "Die thermischen Eigenschaften des gesättigten und des überhitzten Wasserdampfes zwischen 100° und 180°,"—Heft 21, *der Mittheilungen über Forschungsarbeiten*, or *Zeitschr. d. Vereines deutsch. Ing.*, 1905, Oct. 21 and 28, page 1745.

[3] According to Zeuner, it varies approximately as the 0·939 power of the absolute pressure.

where x is the wetness factor and v the specific volume of saturated steam.

Without going into the theory of thermodynamics, a few instances may be given to illustrate the behaviour of steam under various conditions. In accordance with the law of the conservation of energy, we know that when one kilogram of steam has been brought from one state into another, no energy has been created or annihilated. If the total energy belonging to one kilogram of steam in the second state is larger than in the first state, there must have been an input of energy from some external source; and if lower, energy must have been liberated, that is to say, given up to some other object, or changed in form. For instance, one kilogram of saturated steam before expanding in an engine may have an absolute pressure of, say, 13 kilograms per square centimetre, and when leaving the engine a pressure of, say, 0·3 kilogram per square centimetre and a wetness factor of 0·4. From Table XCIII. we find that before expanding the kilogram of steam contained 618 kilogram-calories of energy, and when leaving the engine only $69 + (0 \cdot 6 \times 521) = 382$ kilogram-calories. Therefore in the engine itself the steam must have given up an amount of energy equal to $618 - 382 = 236$ kilogram-calories. If the steam, when entering or when leaving, had an inappreciable speed, we should not have to add to the above value the mechanical energy due to the velocity of the steam, *i.e.* the kinetic energy. For instance, in the above case the speed during expansion in the cylinder behind the piston will be negligible, but during exhaust from the cylinder it may amount to 300 metres per second. In this case the energy in the steam when leaving would be $382 + \left(\frac{300^2}{2 \times 9 \cdot 81}\right)\frac{1}{427} = 382 + 10 \cdot 7 = 393$ kilogram-calories.

The energy given up by one kilogram of steam during expansion in the cylinder is therefore in this case equal to $618 - 393 = 225$ kilogram-calories.

It must be carefully understood that this law does not tell us what has become of the 236 or 225 kilogram-calories that have been given up by the steam. It may have been converted either into mechanical energy or into heat. It is, however, the purpose of a steam engine or a steam turbine to convert as much as possible of the original energy available in the steam into mechanical energy. From this point of view we must ascertain the law according to which the energy available in the steam can be converted into mechanical energy.

For this purpose let us picture to ourselves an experiment in which steam is transformed from one state in which it has a given amount of internal energy, into another state in which it has a less amount. Let the conditions be such as to prevent any of the energy being given up as heat. We thus have the conditions necessary for studying the process of converting internal energy into mechanical energy, as we have cut off all other ways in which the internal energy of the steam can be transformed. The experiment could be of the following nature:—

In a closed cylinder, the sides of which are of non-conducting material, a kilogram of saturated steam has an absolute pressure of p kilograms per square centimetre and a volume of v cubic metres.

Let us now permit the piston to move under the influence of the pressure, the volume increasing to v_1. The work done by the steam in moving the piston is mechanical energy. We shall in this experiment find that part of the steam in the cylinder has been condensed, that is to say, the steam has become wet steam. The pressure has, of course, also decreased. As a rough approximation, we may say that if the volume of the saturated steam has increased in the above experiment by 1 per cent., the pressure has decreased 1·1 per cent., that is, the pressure falls at a slightly higher rate than the volume increases. The exact relation between the two factors is—

$$pv^k = \text{constant, where}$$
$$k = 1{\cdot}135 - 0{\cdot}1x$$
$$(x = \text{the wetness factor}).$$

This can be approximately shown by reference to Table XCIII. Suppose we have saturated steam at an absolute pressure of 10 kilograms per square centimetre, and let it expand in the cylinder described above to 9 kilograms per square centimetre, the total mechanical work done is approximately proportional to the increase in volume multiplied by the mean pressure during the expansion. At 10 kilograms the energy in the steam was 615, at 9 kilograms it is $614 - x \times 437$, where x denotes the wetness factor.

The total energy that has been lost in expanding from 10 kilograms to 9 kilograms per square centimetre is therefore

$$1 + 437x.$$

The volume at 10 kilograms per square centimetre was 0·195,

and at 9 kilograms per square centimetre it is $(1-x)0{\cdot}215$ cubic metres. The increase in volume is therefore

$$(0{\cdot}020 - 0{\cdot}215x) \text{ cubic metres};$$

and as the mean pressure can be taken equal to 9·5 kilograms per square centimetre, the total work done is equal to

$$\begin{aligned} &9{\cdot}5 \times (0{\cdot}020 - 0{\cdot}215x) \times 10{,}000 \text{ metre kilograms} \\ &= (0{\cdot}19 - 2{\cdot}05x)\ 10{,}000 \text{ metre kilograms} \\ &= \frac{(0{\cdot}19 - 2{\cdot}05x)10{,}000}{427} \text{kilogram-calories} \\ &= (4{\cdot}45 - 48x) \text{ kilogram-calories.} \end{aligned}$$

As we know that in no other way can the energy have been decreased, the reduction of energy existing in the steam must equal the mechanical work done, therefore—

$$1 + 437x = 4{\cdot}45 - 48x$$
$$x = \frac{3{\cdot}45}{485} = 0{\cdot}0071$$

Therefore, by adiabatic expansion (*i.e.* by expansion without heat being supplied or taken away) of saturated steam from 10 kilograms per square centimetre to 9 kilograms per square centimetre, 0·7 per cent. of steam has been condensed, $4{\cdot}45 - 48 \times 0{\cdot}0071 = 4{\cdot}11$ kilogram-calories have been converted into mechanical energy, and the volume has increased from 0·195 by $0{\cdot}020 - 0{\cdot}215 \times 0{\cdot}0071 = 0{\cdot}0185$ cubic metres to 0·2135 cubic metres.

The formula $pv^k =$ constant leads to practically the same result.

At 10 kilograms—

$$pv^k = 10 \times 0{\cdot}195^{\ 1{\cdot}135} = 1{\cdot}564$$
$$p_1 v_1^{\ k_1} = 9 \times v_1^{\ 1{\cdot}135 - 0{\cdot}1 \times 0{\cdot}0071} = 1{\cdot}564$$
$$v_1 = 0{\cdot}2139 \text{ (instead of } 0{\cdot}2135 \text{ as before).}$$

For superheated steam a similar relation exists between pressure and volume. The factor k in the formula $pv^k =$ constant has, however, the value 1·3 instead of 1·135 for saturated steam.

A few simple examples worked out will be sufficient to give a student some insight into the behaviour of steam in steam engines and in steam turbines.

Let us consider a steam engine without friction in its moving parts, without radiation and without heat being taken up by the

sides of the cylinder or by the piston. Let us also assume that the pipes between boiler and engine are of so large a section as not to cause any decrease of pressure during the passage of the steam. Let the cylinder be of such dimensions that the weight of the contained steam at the moment of cut-off is 1 kilogram. The absolute pressure is p kilograms per square centimetre. If v is the volume of 1 kilogram of saturated steam at the pressure p, then it is clear that, up to the point of cut-off, the piston has moved through a distance of $\frac{v}{F}$ metres, where F is the area of the piston in square metres. The total force acting through that distance is, if we neglect for the moment the counter-pressure, 10,000 F.p kilogram, therefore the total work done is

$$\frac{v}{F} \times 10{,}000\ Fp = 10{,}000\ pv \text{ (metre kilograms)}$$

$$= 23 \cdot 4\ pv \text{ kilogram-calories.}$$

Suppose the steam to be saturated and $p = 10$ kilograms per square centimetre. Then $v = 0{\cdot}195$ cu. m., and the work done, up to the point of cut-off, is $23{\cdot}4 \times 10 \times 0{\cdot}195 = 46$ kilogram-calories.

Therefore the total energy available in the steam when entering is the internal energy, to be obtained from column 9 of Table XCIII., plus the work done up to the point of cut-off, provided that no decrease of pressure takes place up to that point. We find this total energy to be $615 + 46 = 661$ kilogram-calories. This is precisely the amount of energy necessary to raise the steam, as given in column 18, Table XCIII. Therefore we see that while at the commencement of the admission to the cylinder the amount of energy necessary to produce steam of the prescribed conditions of pressure and temperature was available, at the point of cut-off there is available only the less amount of energy given in columns 4 to 12, and this is the total amount of energy then existing in the steam. We might examine, in exactly the same way as before, the work done during expansion, as we have here, in accordance with our original assumption, the condition that none of the energy can be converted into heat. Let us, however, use the shorter method, and employ the formula

$$pv^k = \text{constant } (k = 1{\cdot}135 - 0{\cdot}1x).$$

If the steam, which at cut-off is at an absolute pressure of 10 kilograms per square centimetre, expands to five times its original

volume before leaving the cylinder, we should conclude that p has decreased to $\frac{1}{6\cdot24}$ times its original pressure, *i.e.* to 1·6 kilograms per square centimetre. The work done during this time is 68 kilogram-calories, as may be found by calculating $p(\Delta v)$[1] step-by-step, or by plotting p as a function of v, and taking the area between the curve of p and the abscissæ, or, better still, by integrating the differential $p \times dv$. There are very ingenious ways of obtaining these results directly from tables, but space will not permit us to further discuss this part of the subject. We see that the total energy converted into mechanical work is $46+68=114$ kilogram-calories, provided that no counter-pressure exists. It is, however, clear that if the engine were working non-condensing, the exhaust pressure would be slightly more than 1 kilogram per square centimetre, and we should have to subtract

$$\underbrace{1\cdot03}_{\text{counter-pressure.}} \times \underbrace{5\times0\cdot195}_{\text{volume of cylinder.}} \times 10{,}000 \text{ m.kg.}$$

$=10{,}000$ metre kilograms $=23$ kilogram-calories. Therefore the total work done would be

$$114-23=91 \text{ kilogram-calories.}$$

If, by means of a condenser, the exhaust pressure is reduced to, say, 0·1 kilogram per square centimetre, the total energy converted into mechanical energy is

$$114-2=112 \text{ kilogram-calories.}$$

In both cases it is clear that more work might have been obtained from the steam by letting it expand to the exhaust pressure, *i.e.* in the first case to 1·03 kilogram and in the second to 0·1 kilogram. This would, in the first case, have led to a slight increase in the amount of mechanical energy obtained, and in the second case to a very great increase. It can be shown, then, that the amount of mechanical work obtained is exactly equal to the difference between the energy necessary to raise the steam to its condition when entering and the energy necessary to raise the steam to its condition when leaving.

The same law holds good in steam turbines, provided that here also no losses take place. But the energy which, in the case of the steam engine, is converted directly into mechanical work, is in

[1] Δv = increase of volume.

the case of a de Laval nozzle first converted into kinetic energy of the steam. For instance, in the case of saturated steam entering at a pressure of 10 kilograms per square centimetre and leaving at 1 kilogram per square centimetre, the mechanical work obtained would be approximately 90 kilogram-calories per kilogram of steam. Therefore the speed of the steam can be obtained from

$$\frac{\text{Velocity}^2}{2 \times 9{\cdot}8} = 90 \times 427$$

$$\text{Velocity} = 868 \text{ metres per second.}$$

It is evident that this calculation may also be applied to

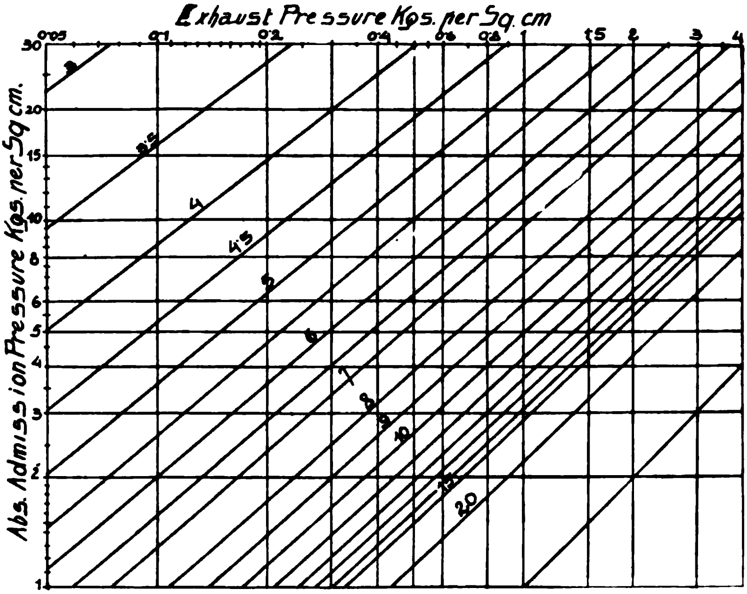


FIG. 236.—Theoretical Consumption of the Perfect Machine. Kgs. per H.P.H. (Metric Units).

See Appendix for Table of Equivalents in Kgs. per K.W.H.

any admission pressure, whether the steam is saturated, superheated, or wet; also to any back pressure.

Professor Rateau gave in his paper "Different Applications of Steam Turbines," Chicago, 1904 (*Proceedings Institution of Mechanical Engineers*), the theoretical consumption of the perfect machine in the following empirical formula for use when the steam is saturated and dry at admission :—

$$K = 0{\cdot}85 + \frac{6{\cdot}95 - 0{\cdot}92 \log P}{\log P - \log p} \text{ (metric units)}$$

$$K = 2{\cdot}13 + \frac{16{\cdot}20 - 2{\cdot}05 \log P}{\log P - \log p} \text{ (English units).}$$

	Metric Units.	English Units.
K = consumption per H.P.Hour	in kgs.	in lbs.
P = absolute admission pressure	„ kgs. per sq. cm.	„ lbs. per sq. in.
p = „ exhaust „	„ „	„ „

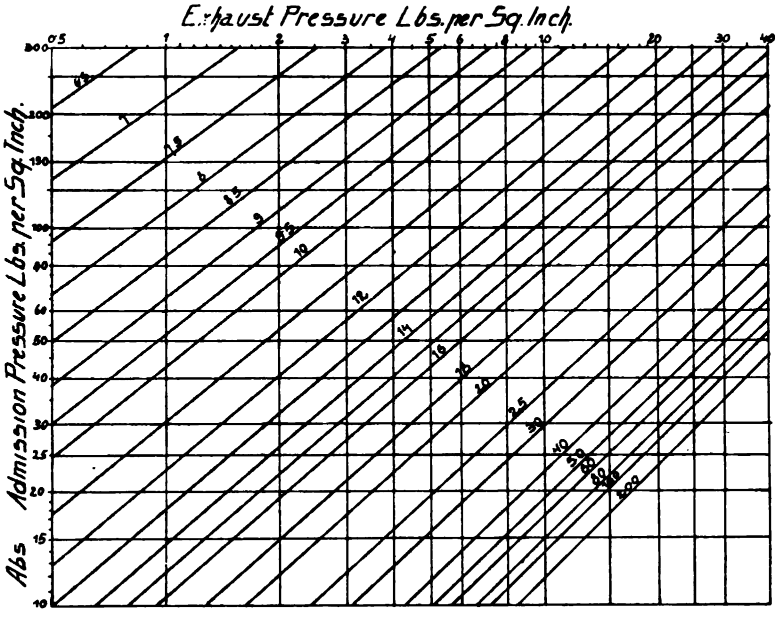


FIG. 237.—Theoretical Consumption of the Perfect Machine. Lbs. per H.P.H.
See Appendix for Table of Equivalents in Lbs. per K.W.H.

Fig. 236 reproduces Professor Rateau's diagram, and Fig. 237 gives the corresponding results in English units. The thermodynamic efficiency of an engine is the ratio of actual steam consumption in any case to the theoretical consumption, the latter being read in Figs. 236 or 237 on the diagonal line which passes through the intersection of the horizontal absolute admission pressure line with the vertical absolute exhaust pressure line.

Fig. 238 shows the volume and pressure of steam at low temperatures.

Fig. 239 shows the properties of water and of saturated steam

expressed in kilowatt-hours. This sheet is similar to, though on a much smaller scale than, the curves recently published by

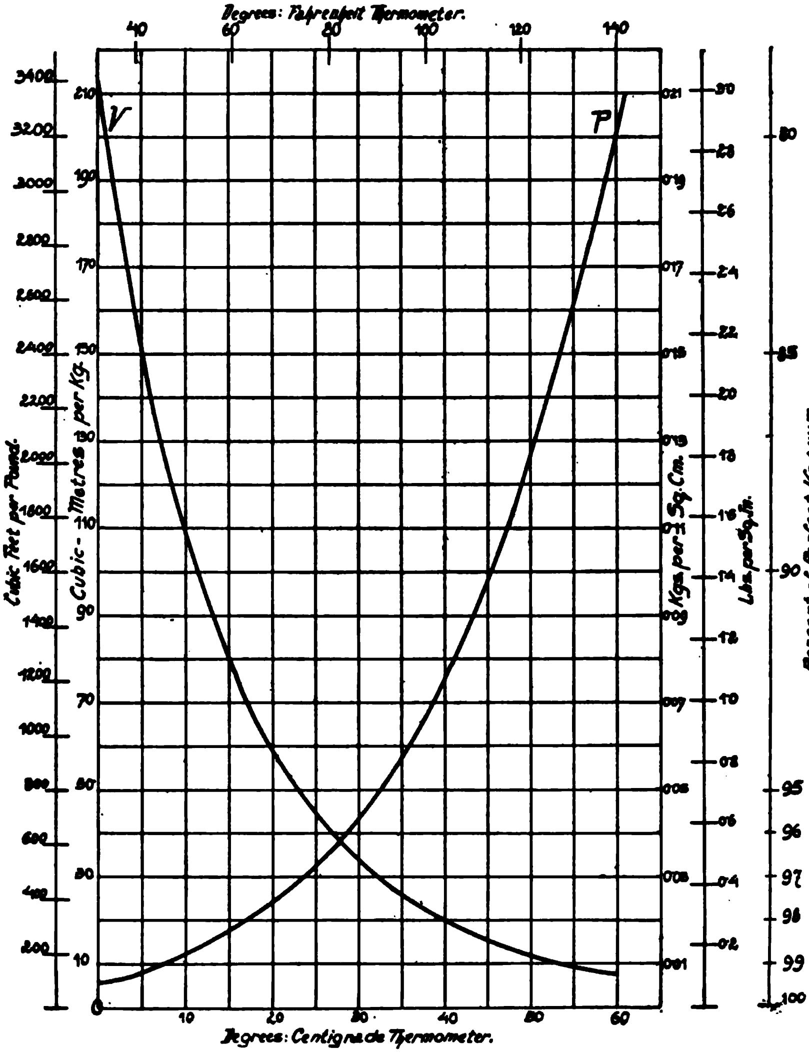


FIG. 238.—Volume and Pressure of Steam at Low Temperatures.

The volume corresponding to a *given* pressure is to be read at the intersection of Curve V with the vertical temperature line which passes through Curve P at that pressure.

Professor R. H. Smith in his *Commercial Economy in Steam and other Thermal Power Plants* (Constable, 1905), in which he used foot-lbs. as his unit.

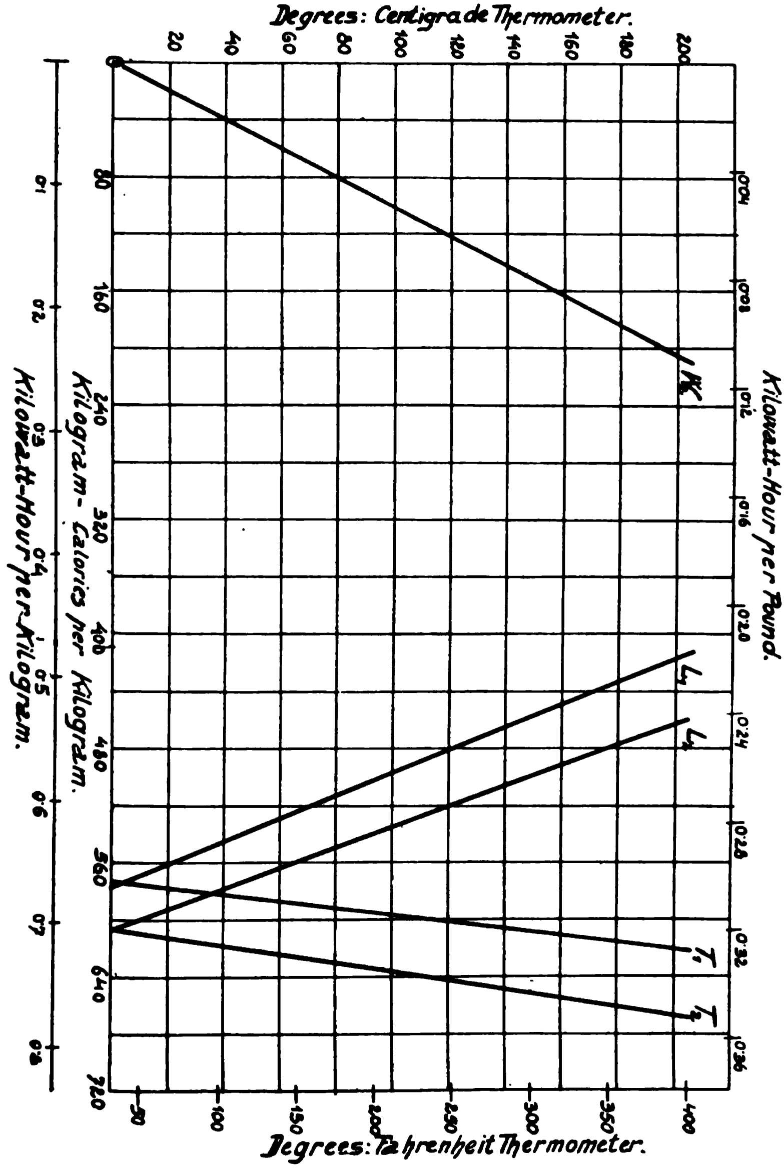


FIG. 239.—Properties of Saturated Steam and Water.

T_2 = Total Heat of Saturated Steam from 32° F. (0° C.).
W_2 = ,, ,, Water ,, ,,
L_2 = Latent ,, Vaporisation from and at each Temperature.
L_1 = ,, ,, ,, less Work done expanding against Pressure.
T_1 = Total ,, Saturated Steam less Work done expanding against Pressure.

CHAPTER XIV

CALORIFIC VALUES OF FUELS

THE calorific values of coals in several countries are given in Table XCV. expressed in several units.

For the electrical engineer, kilowatt-hours per unit of weight is the best way to express this quantity, and it simplifies the mental operations, as elsewhere mentioned, to thus carry through all calculations on a single unit.

TABLE XCV.—CALORIFIC VALUES OF A NUMBER OF VARIETIES OF COAL.

Source.	Nature.	Calorific Value in			
		B.Th.U. per Lb. of Coal.	Kg.C. per Kg. of Coal.	K.W.H. per Lb. of Coal.	K.W.H. per Kg. of Coal.
Wales . . .	Almost pure Anthracite	15,000 to 16,000	8300 8900	4·40 4·68	9·69 10·33
England . .	Bituminous	13,800 to 14,800	7700 8200	4·04 4·33	8·91 9·55
Scotland . .	Bituminous	13,000	7200	3·80	8·39
United States of America	Anthracite	14,000	7800	4·10	9·04
	Average Bituminous	13,500	7500	3·95	8·72
Germany . .	Cannel coal	11,000 to 14,500	6100 8100	3·22 4·24	7·10 9·36
	Bituminous	12,600	7000	3·69	8·13
	Braunkohle (hard lignite)	9,700	5400	2·84	6·26
	Braunkohle (soft lignite)	6,500	3600	1·90	4·20

We have expressed the calorific value in a number of different units, as of possible convenience to engineers, but we prefer to express it in terms of the "kilowatt-hours per kilogram of coal." This gives the total amount of heat energy made available by burning one kilogram of coal with a suitable supply of air.

Now, were it possible to construct a boiler with 100% efficiency, the kilograms of steam raised by one kilogram of coal could be readily derived from Table XCIII. or XCIV., pp. 342, 345. For our standard pressure of 13 kilograms per square centimetre (absolute) and 50° C. of superheat (185 lbs. per square inch and 90° F. superheat), we see that 698 kilogram-cals. or 0·815 kilowatt-hours are required to obtain one kilogram of steam, on the theoretical basis that water of 0° C. is supplied to the boiler, and that the superheater is heated from the same fire as the boiler.

Generally, however, water is supplied to the boiler at a considerably higher temperature. Thus the temperature of water, if taken directly from a river, will generally vary between 0° C. and 25 C. (32° and 77° F.), and if taken from the condenser it will vary between 40° C. and 60° C. (104° and 140° F.). Moreover, the feed water is often heated before being supplied to the boiler in order to reduce the loss of heat in the gases, as otherwise they would leave at a very much higher temperature than the temperature in the boiler. We are, however, justified in saying that this latter means serves only to increase the efficiency of the boiler, while the coal must in any case supply sufficient heat to produce one kilogram of steam from water of, say, 50° C. To produce a kilogram of steam at 13 kilograms absolute pressure and 50° C. superheat, from water at a temperature of 50° C., requires 648 kilogram-calories (Kg.-cals.), or 0·755 kilowatt-hours. Coal having a calorific value of 7500 kilogram-calories or 8·7 kilowatt-hours per kilogram would, with 100% boiler efficiency, raise to specified conditions $\left(\frac{8{\cdot}7}{0{\cdot}755}\right) = 11{\cdot}5$ kilograms of steam.

Without entering upon a study of the losses diminishing the efficiency, it will suffice to say that in large, well-designed boilers, the efficiency of the steam-raising plant, including economiser and superheater, will be between 60% and 80%, and the number of kilograms of steam obtained in such a boiler per kilogram of coal burned is between 6·9 and 9·2 kilograms for the conditions specified above.

For other conditions of pressure and temperature of steam, the steam raised per kilogram of coal burned will vary in inverse

proportion to the heat required. In testing boilers, it has become customary to base figures on saturated steam at atmospheric pressure, and to further assume that the feed water has a temperature of 100° C. (from and at 212° F.).

Consulting the table above referred to, we find the heat necessary to raise one kilogram of steam to these conditions to be 537 kilogram-calories, or 0·625 kilowatt-hours. This permits us to deduce the values set forth in Table XCVI.

TABLE XCVI.

Boiler Efficiency.	Kgs. of Steam raised per one Kg. of Coal burned (the Coal has a Calorific Value of 7500 Kg.-cals.).
100 per cent.	14
70 „	9·8
60 „	8·4

The foregoing values are generally denoted in the metric system as—kilograms of steam "from and at 100° C." per kilogram of coal.

In the English system it is customary to speak of the—lbs. of steam "from and at 212° F." per lb. of coal.

The general range, in different parts of Great Britain, of the price of coal of an average calorific value of 8·7 kilowatt-hours (7500 kilogram-calories) per kilogram, is from 4 to 16 shillings per ton of 1000 kilograms (2200 lbs.). For our standard conditions of steam—an absolute pressure of 13 kilograms per square cm. and 50° C. of superheat, and with feed water at 50° C.—we shall, with coal of this quality and steam-raising plant of 60%, 70%, and 80% efficiency, get 6930, 8120, and 9280 kilograms of steam per ton of coal. From column 2 of Table XCVII. we can, for coal of this quality, at various prices in shillings per ton delivered on site, obtain the cost for fuel in shillings per 1000 kilograms of steam produced. In columns 3 to 10 are set forth the corresponding fuel costs in pence per kilowatt-hour generated, for the case of steam-driven sets when operating with steam consumptions of 6 to 20 kilograms of steam per kilowatt-hour of output.

If the feed water supplied to the boiler has a temperature other than 50° C. before entering the boiler, the values given in Table XCVII. require to be altered slightly. For instance, if the temperature of the feed water is 10° C., the values in columns

TABLE XCVII.

Cost in Shillings per Ton delivered on site for Coal of a Calorific Value of 8·7 Kilowatt-hours per Kg. equal to 7,500 Kilogram-calories per Kg.; 13,500 British Thermal Units per lb.	Outlay for Fuel (in Shillings per 1000 Kilograms of Steam raised) in producing (from feed water at 50° Cent.) Steam at an absolute pressure of 13 Kgs. per sq. cm. and 50° Cent. Superheat.	Cost of Coal in Pence per Kilowatt-hour (absolute pressure of Steam 13 Kgs. per sq. cm. 50° Cent. Superheat, Feed Water 50° Cent.) at the Steam Consumption of (stated at the top of column). Kilograms per Kilowatt-hour.							
		6	8	10	12	14	16	18	20
For a Boiler Efficiency of 60%.									
4s.	·57	·041	·055	·069	·083	·097	·111	·124	·138
5s.	·71	·052	·069	·086	·103	·121	·138	·155	·175
6s.	·86	·062	·083	·104	·124	·145	·166	·186	·207
7s.	1·05	·072	·097	·121	·145	·169	·193	·217	·242
8s.	1·15	·083	·110	·138	·166	·193	·221	·248	·276
9s.	1·30	·093	·124	·155	·187	·217	·248	·280	·310
10s.	1·44	·104	·138	·173	·207	·241	·276	·310	·345
11s.	1·58	·114	·152	·190	·228	·266	·304	·342	·379
12s.	1·72	·124	·166	·207	·249	·290	·331	·373	·414
13s.	1·87	·134	·180	·224	·269	·314	·359	·404	·448
14s.	2·10	·145	·193	·242	·290	·338	·386	·435	·483
15s.	2·16	·155	·207	·259	·311	·362	·414	·466	·517
16s.	2·30	·165	·221	·276	·331	·386	·441	·497	·552
For a Boiler Efficiency of 70%.									
4s.	·49	·036	·047	·059	·071	·083	·095	·106	·118
5s.	·61	·044	·059	·074	·089	·103	·118	·133	·148
6s.	·74	053	·071	·089	·107	·124	·142	·160	·178
7s.	·86	·062	·083	·103	·124	·145	·166	·186	·207
8s.	·98	·071	·095	·118	·142	·166	·190	·213	·237
9s.	1·11	·080	·106	·133	·160	·187	·213	·240	·266
10s.	1·23	·089	·118	·148	·178	·207	·237	·267	·295
11s.	1·35	·098	·130	·162	·195	·228	·261	·294	·325
12s.	1·47	·107	·143	·177	·213	·249	·285	·320	·355
13s.	1·60	·115	·154	·192	·231	·269	·310	·346	·385
14s.	1·70	·124	·166	·207	·249	·290	·334	·373	·415
15s.	1·82	·133	·177	·222	·266	·310	·357	·400	·444
16s.	1·96	·142	·189	·236	·284	·331	·380	·426	·474

TABLE XVCII.—*continued.*

	Cost in Shillings per Ton delivered on site for Coal of a Calorific Value of 8·7 Kilowatt-hours per Kg., equal to 7,500 Kilogram-calories per Kg.; 13,500 British Thermal Units per Lb.	Outlay for Fuel (in Shillings per 1000 Kilograms of Steam raised) in producing (from feed water at 50° Cent.) Steam at an absolute pressure of 13 Kgs. per sq. cm. and 50° Cent. Superheat.	Cost of Coal in Pence per Kilowatt-hour (absolute pressure of Steam 13 Kgs. per sq. cm., 50° Cent. Superheat, feed water 50° Cent.) at a Steam Consumption of Kilograms per Kilowatt-hour.							
			6	8	10	12	14	16	18	20
For a Boiler Efficiency of 80 %.	4s.	·43	·031	·041	·052	·062	·072	·083	·093	·103
	5s.	·54	·039	·052	·065	·078	·091	·104	·116	·130
	6s.	·64	·046	·061	·078	·093	·109	·124	·139	·155
	7s.	·75	·054	·072	·091	·109	·127	·145	·162	·182
	8s.	·86	·062	·083	·104	·124	·145	·166	·186	·206
	9s.	·96	·070	·093	·117	·140	·163	·186	·210	·233
	10s.	1·08	·078	·103	·130	·155	·181	·206	·234	·260
	11s.	1·18	·085	·114	·143	·171	·200	·227	·257	·285
	12s.	1·29	·093	·124	·156	·186	·218	·248	·280	·310
	13s.	1·40	·101	·135	·169	203	·236	·269	·304	·337
	14s.	1·50	·109	·145	·182	·218	·254	·290	·327	·364
	15s.	1·61	·116	·156	·195	·233	·272	·311	·350	·390
	16s.	1·72	·124	·166	·207	·248	·290	·331	·372	·414

2 to 10 must be increased by 6%. Table XCVIII. gives such corrections.

The efficiency of the boiler has been given as varying between 60% and 80%. It is as well to distinguish between the efficiency of the boiler as measured by test and the all-year efficiency of the boiler. While, in the first case, the efficiency is very often as high as 75% or 80%, the same boiler may give an all-year efficiency of only 50% or 60%, and in some cases considerably lower still. Very often the boilers must be kept under pressure for a long time without any work being done, and it is clear that in this case the losses due to radiation, which normally rarely exceed 5% to 10%, would increase in importance. The authors have compiled a table in which are recorded the results for the actual all-year coal consumption per kilowatt-hour for some stations. All this data has been obtained directly from the Engineers of the generating

TABLE XCVIII.

Temp. in degs. Cent. of Water supplied to Boiler.	Per Cent. Change of the Values in Columns 2 to 10 of Table XCVII.
0	+7·5 per cent.
10	+6 „
20	+4·5 „
30	+3 „
40	+1·5 „
50	0
60	−1·5 „
70	−3 „
80	−4·5 „

stations. The results throw some light on the actual cost of fuel in its relation to the kilowatt-hours supplied.

The following analysis was given by Mr H. G. Stott in "Power Plant Economics," *Proceedings of the American Institute of Electrical Engineers*, January 1906, of the losses in a year's operation of one of the most efficient plants in existence to-day, for which coal has been purchased during two years on the basis of the B.Th.U., it gives on tests of samples taken automatically on delivery of each charge to the power-house weighing-hopper.

AVERAGE LOSSES IN CONVERTING ENERGY IN 1 LB. OF COAL INTO ELECTRICAL ENERGY.

	B.Th.U.	Per cent.	B.Th.U.	Per cent.
1. B.Th.U. per pound of coal supplied	14,150	100·	..	..
2. Loss in ashes	..	..	340	2·4
3. „ chimney	..	..	3,210	23·
4. „ boiler radiation and leakage	..	..	1,130	8·0
5. Returned by feed water heater	440	3·1	..	..
6. „ economiser	960	6·8	..	..
7. Loss in pipe radiation	..	..	28	0·2
8. Delivered to circulator	..	..	220	1·6
9. „ feed pump	..	..	200	1·4
10. Loss in leakage and high-pressure traps	..	..	150	1·1
11. Delivered to small auxiliaries	..	..	51	0·4
12. Heating	..	..	31	0·2
13. Loss in engine friction	..	..	111	0·8
14. „ electrical	..	..	36	0·3
15. „ engine radiation	..	..	28	0·2
16. Rejected to condenser	..	..	8,520	60·
17. To power-house auxiliaries	..	..	29	0·2
	15,550	109·9	14,080	99·8
	14,084	99·8	..	..
18. Delivered to bus-bar	1,470	10·1	..	..

TABLE XCIX.—COAL COST AND QUALITY USED IN SOME ELECTRICITY PLANTS.

Reference Number.	Name.	Coal used. Calorific Value B.Th.U. per Lb.	Price per Ton, Shillings.	Lbs. per K.W.H. at Switchboard.	Water. Lbs. evaporated per Lb. of Coal.
6	**Carville**	11,000	5·75	...	...
8	**Quincy Point**	14,000	14·6	2·8	...
13	Halifax	...	6·6	...	...
15	**Sheffield Neepsend**	12,000	...	3·5/4	4·5/5·5
16	**Los Angeles U.S.A.**	18,000 dry oil	0·8d gallon	2·6	...
17	**Brimsdown**	12,000	11·75	5	...
20	*Harrogate*	12,000	12	6·7	7·5
22	*Middlesboro'*	...	9·5	7·2	6·8
23	**Shipley**	11,500	7·1	...	...
24	*Kidderminster*	...	8·8	10	...
35	Interboro (Subway), New York	15,000	...	...	...
36	Manhattan Elevated, New York	15,000	...	...	...
37	Manchester, Dickenson St.	13,900	10	4·5	8·8
39	Leeds	11,000	5	8	7
40	Pinkston	12,600	6·25	3	7·5
41	Kansas City, Met. S.R. Co.	13,000	6·2	3·7	7·5 from and at 212° F.
42	Salford	14,500	7·7	4·1	...
43	Westham	13,000	8·2 to 13·2	5	8
45	Kelham Is., Sheffield	12,000	8·2	3·8	8·1
46	Alpha Place, Chelsea	14,500	21	4·6	9
47	Lowell, U.S.A.	14,300	18·4	2·6	9·1 10·9 from and at 212° F.
49	Dundee	11,500	8·1	4·8	6·2
50	Paisley	13,000	7·3	8·8	10·2
51	Wimbledon	...	21·9 Welsh 15·5 Derby Nuts	6	7
52	Reading	...	20	5·9	9·2
53	Ilford	..	20·5 Welsh 16·5 Mardy	4·1	8·7
55	Leicester	8,000	5·5	4	7
56	Wolverhampton	12,000 12% ash	5·8	6·32	7·2 from and at 212°
57	Greenock	11,700	8·1	7·4	...
58	Eastham, London	...	13·75	5·7	6·7
59	Lowestoft	...	17	4·7	8·4
60	Burton-on-Trent	...	4	8·8	7

TABLE XCIX.—*continued.*

Reference Number.	Name.	Coal used.			Water.
		Calorific Value B.Th.U. per Lb.	Price per Ton, Shillings.	Lbs. per K.W.H. at Switchboard.	Lbs. evaporated per Lb. of Coal.
61	Hull Tramways	...	10	...	...
62	Stalybridge	...	8·2	4	7·5
63	Burnley	14,000	10	4·5	9·5 test
64	Walsall	...	7·7	...	...
65	Bury, Lancs	...	6·7	...	...
66A	Eastbourne	14,000	24·1	6	8·8
67	Gloucester	12/13,000	10	5/6	5 to 6
68	Kirkcaldy	13,000	7·2	...	...
69	Barrow-in-Furness	14,000	11	6	7
72	Gillingham	...	9·7 14·5	13·6	...
73	Carlisle	...	...	9·5	7
74	Chatham	14,000	15·5	4	8·5
75	Barnes	14,800	19·9	4	10
76	Worthing	12,000	19·9	5	...
77	Guernsey, Les Amballes	13,000	16	5·2	...
	St Sampson	13,000	16	2·2	Gas
78	Cleethorpes	11,500 Shirebrook	8	...	...

R. W. Allen's Test 14,300 B.Th.U. "Rheola." 7960 Kg.C. per Kg., *Inst. C.E.*, "On Surface Condenser Plants," Feb. 28, 1905.

CHAPTER XV

TYPICAL RESULTS AS TO STEAM ECONOMY IN MODERN PISTON ENGINES

FOUR representative firms of piston engine builders in England, designated in this chapter as firms A, B, C, and D, have very

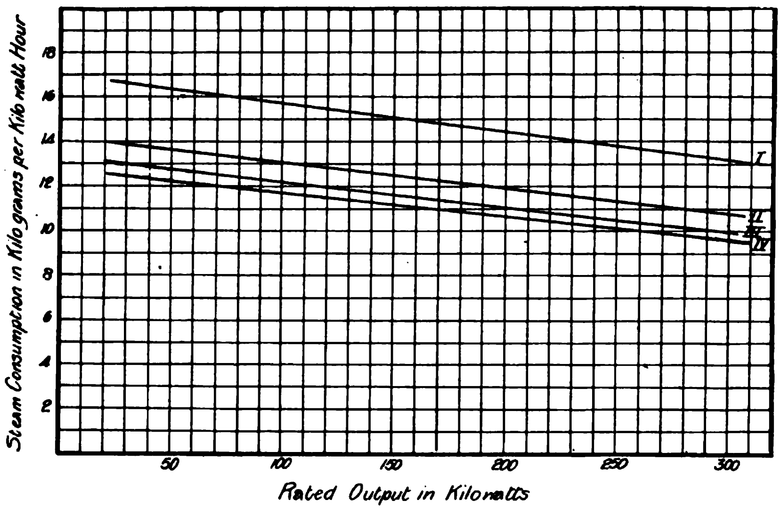


FIG. 240.—Steam Consumption: Firm A's Reciprocating Engines.
13·4 Kgs. per Sq. Cm. Absolute, 55·5° C. Superheat, 86·6 per cent. Vacuum.
I = Quarter Load; II = Half Load; III = Three Quarters Load; IV = Rated Full Load.

kindly furnished us with their guarantees as regards steam consumption. Firm A builds small engines. Their guarantees, expressed in terms of the kilograms steam consumption per kilowatt-hour output from a hypothetical direct-connected generator, have been plotted in the curves of Fig. 240. Firms B and C

manufacture fairly large sizes of engines, and their guarantees are to be found in the curves of Figs. 241 and 242.

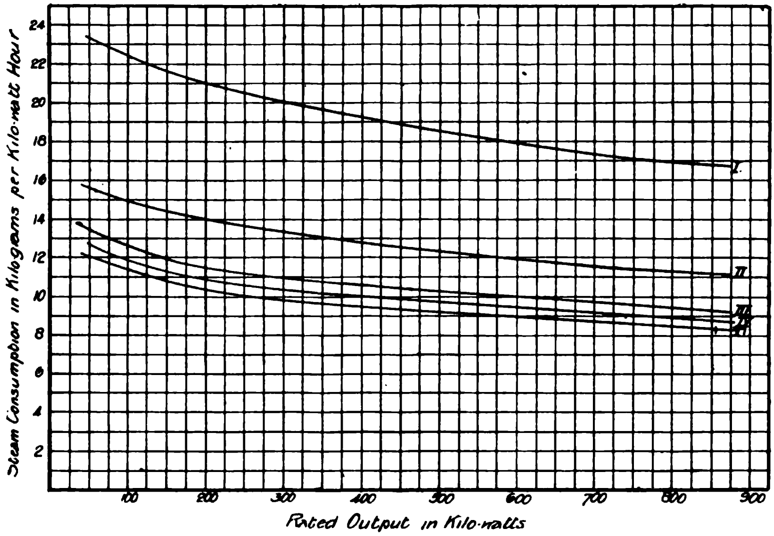


FIG. 241.—Steam Consumption of Firm B's Reciprocating Steam Engines. 13·4 Kgs. per Sq. Cm. Absolute, 53° C. Superheat, 86·6 per cent. Vacuum. I = Quarter Load ; II = Half Load ; III = Three Quarters Load ; IV = Full Rated Load ; V = 25 per cent. Overload.

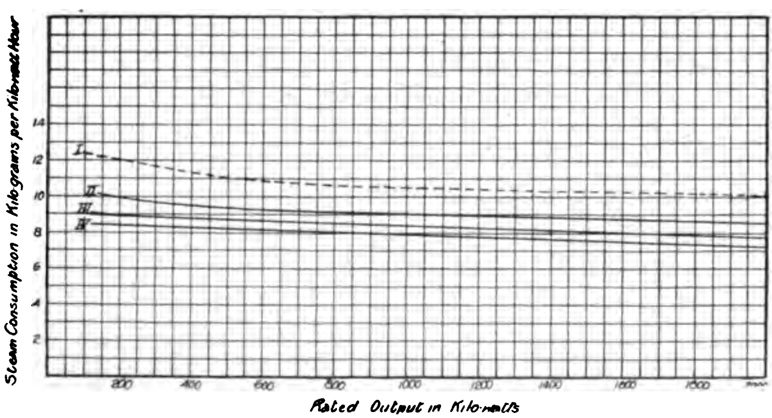
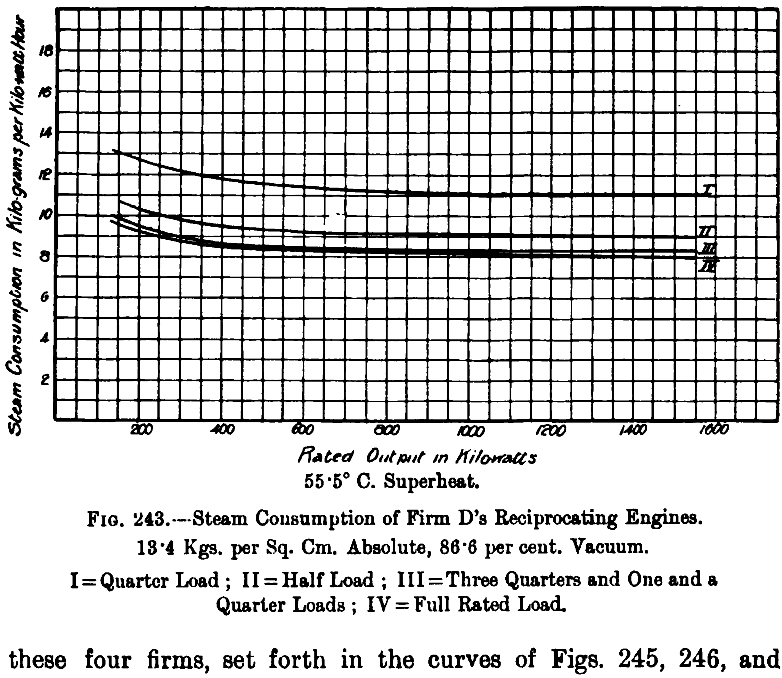


FIG. 242.—Firm C's Reciprocating Steam Engines. Steam Consumption at 14·4 Kgs. per Sq. Cm. Absolute, 55·5° C. Superheat, 86·6 per cent. Vacuum. IV = Rated Full Load ; III = One and a Quarter and Three Quarters Loads ; II = Half Load ; I = Quarter Load estimated from the other Curves.

Firm D also builds engines up to large sizes, and they have furnished us with guarantees not only with superheat of 55·5° Cent., but also of 111° Cent. These guarantees will be found plotted in the curves of Figs. 243 and 244.

It will be noticed that the conditions under which these various guarantees have been made correspond closely with our standard basis of reference, namely, for an absolute steam pressure of 13 kilograms per square centimetre, with a vacuum of 86·6 per cent. and 50° C. of superheat. The steam consumption under these standard conditions for full, half, and quarter loads are, for



55·5° C. Superheat.

FIG. 243.—Steam Consumption of Firm D's Reciprocating Engines.
13·4 Kgs. per Sq. Cm. Absolute, 86·6 per cent. Vacuum.
I = Quarter Load ; II = Half Load ; III = Three Quarters and One and a Quarter Loads ; IV = Full Rated Load.

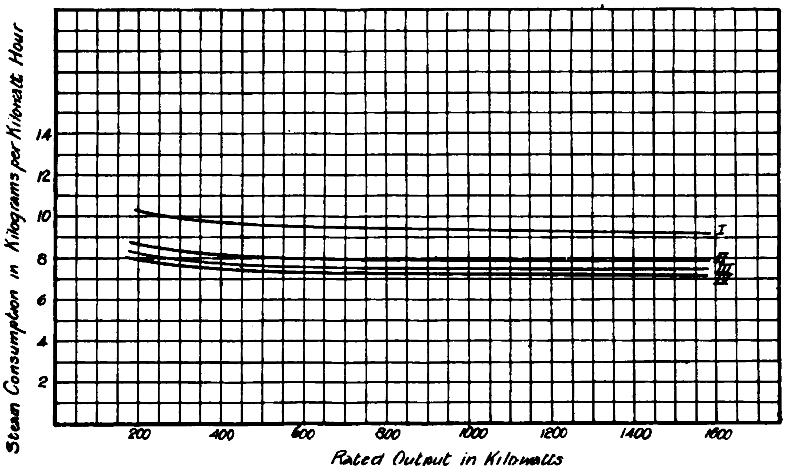
these four firms, set forth in the curves of Figs. 245, 246, and 247. The dotted-line curves in these three figures roughly represent the mean steam consumptions for engines of the four firms A, B, C, and D.

Guided by the data in Figs. 245, 246, and 247, we have deduced the three curves I, II, and III of Fig. 248, corresponding to the dotted curves of the three previous figures, as fairly representing the steam consumption for this group of modern piston engines at one quarter, one half, and full loads respectively.

In an article entitled, "Die Dampfturbinen der Allgemeinen Elektricitäts-Gesellschaft, Berlin" (*Zeitschr. des Vereines deutscher*

Ingenieure, August 13th, 1904, p. 1209, Fig. 5), Lasche has published a curve which he states represents the rated full-load steam economy of good modern piston engines at an absolute admission pressure of 13 kilograms per square centimetre, with "some superheat and good vacuum." Lasche's curve is given in Fig. 249 as curve L, and the rated full-load curve of Fig. 248 is reproduced as curve III.

Full Load Steam Consumption: Piston Engines.—We have also compiled in Table C. the full-load steam consumptions of thirty-three piston engines of 19 different manufacturers



111° C. Superheat.

FIG. 244.—Steam Consumption of Firm D's Reciprocating Engines. 13·4 Kgs. per Sq. Cm. Absolute, 86·6 per cent. Vacuum. I = Quarter Load; II = Half Load: III = Three Quarters and One and a Quarter Loads; IV = Full Rated Load.

of five different countries. Most of this data was derived from published results. In a few cases the guarantees of the makers were employed. To afford a common basis of comparison, the results were reduced, by correction curves which will be described later in this chapter, to terms of the steam consumption for our standard reference conditions of an absolute admission pressure of 13 kilograms per square centimetre (corresponding to a gauge pressure of 170 pounds per square inch), with a superheat of 50° Cent. (90° Fahr.), and with an 86·6 per cent. (26 inches, or 660 millimetres) vacuum. Where the results were expressed in terms of the indicated horse-power or brake horse-power, we reduced

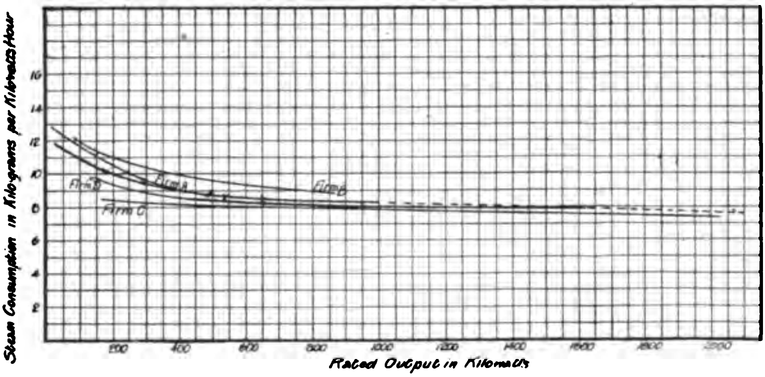


Fig. 245.—Full Rated Load.

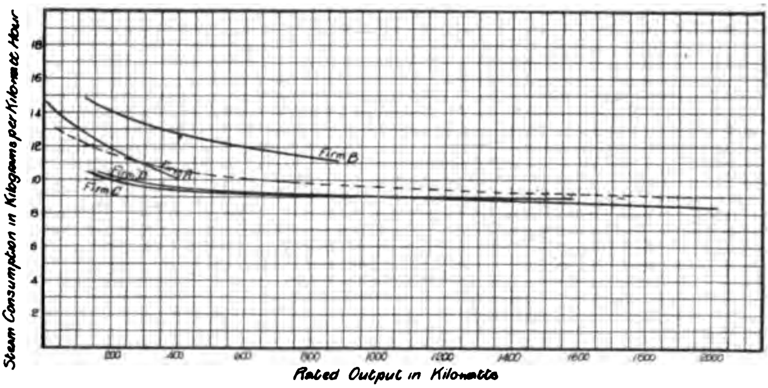


Fig. 246.—Half Rated Load.

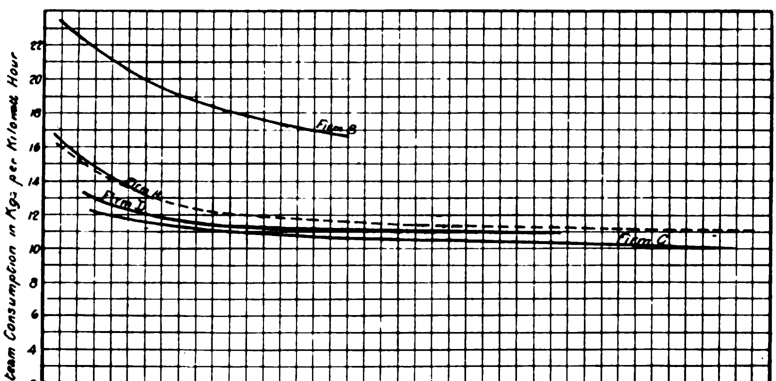


Fig. 247.—Quarter Rated Load.

Figs. 245, 246 and 247.—Steam Consumption of Reciprocating Engines.

50° C. Superheat, 86·6 per cent. Vacuum.
A, B, and D, 13·4 Kgs. per Sq. Cm. Absolute.
C, 14·4 ,, ,,
Dotted Curve is the Mean of the Four Full Lines.

them, by means of the efficiency assumptions already described in Chapter III., to terms of the kilowatts output from a direct-

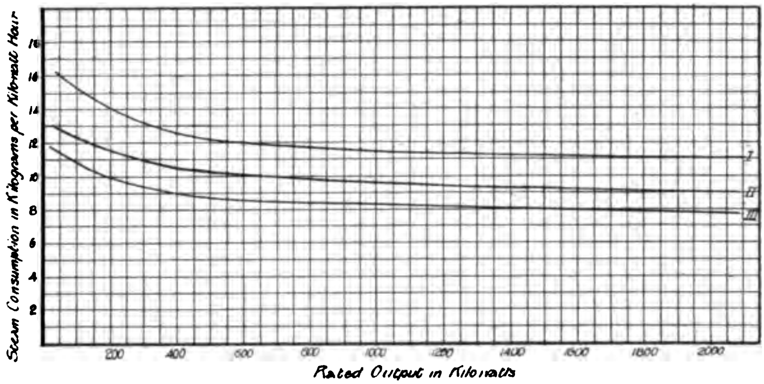


FIG. 248.—Mean Steam Consumption for Four Firm's Reciprocating Engines. 13 Kgs. per Sq. Cm. Absolute, 50° C. Superheat, 86·6 per cent. Vacuum. I = Quarter Load ; II = Half Load ; III = Rated Full Load.

connected dynamo. The 33 generating sets thus considered, ranged in output from 140 kilowatt to 5000 kilowatt. No tests in which

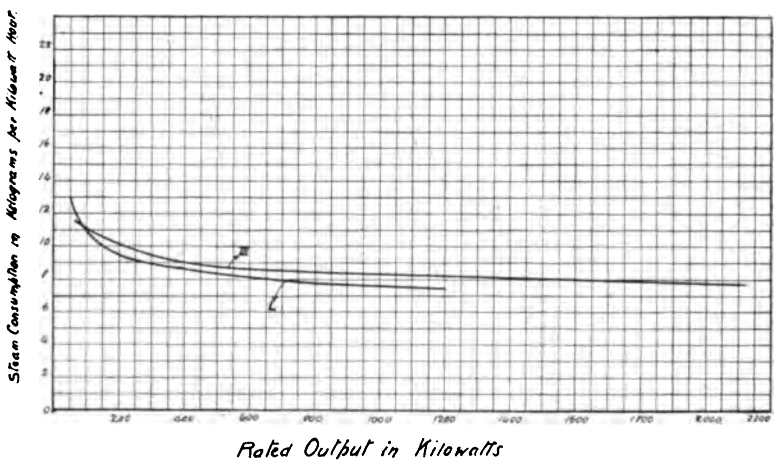


FIG. 249.—Steam Consumption of Reciprocating Engines at Rated Full Load. III is from Fig. 248. L = Lasche, see p. 373.

the steam consumption, when reduced to our standard conditions, was over 9·0 kilograms (19·8 lbs.) per kilowatt-hour output at rated load were included.

TABLE C.—DETAILS OF RESULTS DERIVED FROM PUBLISHED

Reference No. of Engine.	Rated Output reduced to Terms of Kilowatts from Dynamo.	Speed in Revs. per Min.	Admission Pressure (absolute) in Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Superheat at Admission in Degrees Centigrade.	Steam Consumption in Kgs. per K.W. Hour Output from Dynamo.	Steam Consumption in Kgs. per K.W. Hour reduced to the Standard Conditions adopted in this Comparison. (Estimated.)	Date of Test. Test Conducted by	Where installed.
1	140	...	10·3	·073	172	6·35	8·0	Prof. Schroeter	...
2	153	35	11·6	...	0	8·5	7·3	1900 Prof. Unwin	Leicester Water Works
3	158	126	10·2	·077	0	9·8	8·6	...	...
	158	126	10·2	·077	37	9·0		...	...
	158	126	10·2	·077	102	8·0		...	...
	158	126	10·2	·077	190	6·6		...	...
4	163	...	11·6	...	0	8·35	7·2	Prof. Thurston	...
5	190	140	10·5	·091	107	7·0	8·0	Dec. 16, 17/02 Prof. Ewing	Near Manningtree
6	220	350	13·0	·167	85·6	8·4	8·9	...	Lincoln
7	264	472	12·3	·089	175	7·45	8·9	...	...
8	325	100	9·3	·118	140	6·35	7·2	M. Longridge	Belfast
9	385	66	7·55	·072	0	10·4	8·2	May 25, 1893	Augsburg
	385	66	7·53	·087	68·0	8·65		May 25, 1893	Do.
	385	66	7·59	·082	75·7	8·4		May 25, 1893	Do.
10	400	375	11·1	·20	0	9·7	7·9	...	Leeds
11	400	150	11·7	·134	0	9·15	7·8	...	...
12	440	68·5	12·2	·073	0	7·4	6·7	Feb. 5, 1902	...
13	600	120	11·6	·044	0	8·9	8·0	Prof. Jacobus of Hoboken	...
14	625	101	14·6	·130	50	7·77	8·0	...	Newcastle-upon-Tyne
15	700	101	14·6	·144	50	8·00	8·2	...	Wallsend
16	720	80	15·0	·130	48·5	7·75	8·0	May 5, 1901	Do.
17	770	67	13·2	·094	61	6·9	7·3	Mar. 3, 1903	Erlangen

Where blank spaces have been left, the values have not been ascertained. In such cases, in order been estimated

TESTS, ESTIMATES, AND GUARANTEES BY MAKERS.

Manufacturer of the Steam Engine.	Type of Piston Engine.	Source of Data.
Kerchove	Horizontal Tandem Compound	Paper by C. V. Kerr, Amer. Soc. Mech. Engrs., vol. xxv.
Hawthorn, Davey & Co.	Pumping Engine	*The Engineer*, April 28, 1905, p. 416.
Kerchove	Slow-speed Compound	*The Engineer*, January 8, 1904, p. 47.
Do.	Do.	Do. do. do.
Do.	Do.	Do. do. do.
Do.	Do.	Do. do. do.
Milwaukee	Pumping Engine	*The Engineer*, April 28, 1905, p. 416.
Easton & Co.	Horizontal Tandem 2-cylinder Compound	*The Engineer*, January 9, 1903, p. 46.
James Howden & Co.	High-speed Triple Expansion	*El. Review*, August 18, 1905, p. xxv.
Bellis & Morcom	Do.	*The Engineer*, July 28, 1905, p. 78.
Cole, Marchent & Morley	Vertical Cross Compound	*The Engineer*, June 2, 1905, p. 548.
Werk Augsburg	Slow-speed Compound	*Zeitschrift des Ver. Deut. Ing.*, August 12, 1905, p. 1316.
Do.	Do.	
Do.	Do.	
James Howden & Co.	High-speed Triple Expansion	*El. Review*, August 18, 1905, p. xxv.
Harrisburg Foundry and Machine Works	Tandem Compound	*Trans. Amer. Soc. Mech. Engrs.*, vol. xxv., Dec. 1903, pp. 1–16.
Werk Augsburg	Slow-speed Triple Expansion	*Z. d. V. Deut. Ing.*. Aug. 19/05, p. 1350.
Rice & Sargent	Compound Corliss	*El. Review*, April 8, 1905, p. 575.
Wallsend Slipway and Eng. Co.	Slow-speed Triple Expansion	*Proc. Inst. Mech. Engrs.* at Newcastle. By W. B. Woodhouse.
Do.	Do.	*Proc. Inst. Civil Engrs.*, vol. cli. p. 200. By T. H. Minshall.
Hick, Hargreaves & Co.	3-crank Triple Expansion	*The Engineer*, July 7, 1905, p. 2.
Werk Augsburg	Slow-speed Triple Expansion	*Z. d. V. Deut. Ing.*, Aug. 19/05, p. 1352.

to calculate the steam consumptions reduced to our standard conditions, the missing details have and assumed.

TABLE C.—

Reference No. of Engine.	Rated Output reduced to Terms of Kilowatts from Dynamo.	Speed in Revs. per Min.	Admission Pressure (Absolute) in Kgs. per Sq. Cm.	Exhaust Pressure in Kgs. per Sq. Cm.	Superheated Admission in Degrees Centigrade.	Steam Consumption in Kgs. per K. W. Hour Output from Dynamo.	Steam Consumption in Kgs. per K. W. Hour reduced to the Standard Conditions adopted in this Comparison. (Estimated).	Date of Test. Test Conducted by.	Where installed.
18	790	102	13·3	·10	72·5	7·64	8·2	...	...
19	850	90	9·31	·239	13·5	8·9	7·3	Aug. 8, 1901	Weisbaden
	850	90	9·41	·20	59·2	8·1		Aug. 16, 1901	Do.
20	910	60	13·3	·077	42·5	7·77	8·4	May 13, 1900	...
21	1070	83	10·4	·074	0	8·3	8·6	June 9, 1903	Strasburg
22	1135	88	13·6	·10	82·5	8·45	9·0	...	...
23	1170	90	9·62	·29	22·6	9·6	7·5	Aug. 14, 1901	Weisbaden
	1170	90	8·94	·236	71·8	8·2		Aug. 17, 1901	Do.
24	1400	...	13·7	·144	39	8·5	8·3	...	Leeds
25	1500	...	12·3	·155	0	9·3	7·9	March 1903	Manchester Corporation
26	1600	100	12·1	·190	51·3	7·5	7·1	Sept. 20, 1901	...
27	1900	83	14·5	...	0	8·3	7·7	Oct. 19, 1899	Berlin
	1900	83	14·2	...	83	7·25		Oct. 18, 1899	Do.
	1900	83	14·1	...	129	6·75		Oct. 24, 1899	Do.
28	2600	86	10·3	·082	0	7·9	6·9	...	...
	2600	86	10·3	·082	121	6·45		...	...
	2600	86	10·3	·082	171	5·9		...	...
29	2800	75	11·6	·100	0	8·64	7·5	Apr. 1, 1902 Prof. Barr	Glasgow Tramways
30	3200	94	13·7	·130	85	8·15	8·9	...	Greenwich
31	3800	76	14·0	·105	0	7·7	7·1	Feb. 1904 Andrew Witham and Wells	New York—Edison Plant
32	3900	75	14·4	·105	65·5	7·7	8·3	...	Manchester Corporation
33	5000	75	13·4	·130	0	8·5	7·5	...	New York

Where blank spaces have been left, the values have not been ascertained. In such cases, in order been estimated

[1] These are apparently not test results, but

continued.

Manufacturer of the Steam Engine.	Type of Piston Engine.	Source of Data.
Mansfield	Slow-speed Triple Expansion	*Zeit. f. d. Ges. Turb.*, Aug. 1/05, p. 228.
Werk Augsburg	Slow-speed Tandem	*Zeit. des Ver. Deut. Ing.*, Aug 12/05, p. 1312.
...	Do.	
Hick, Hargreaves & Co.	Horizontal Compound	*The Engineer*, July 7, 1905, p. 2.
Werk Augsburg	Slow-speed Triple Expansion	*Z. d. V. Deut. Ing.*, Aug. 19/05, p. 1352.
...	Do.	*Z. f. d. Ges. Turb.*, Aug. 1/05, p. 228.
Werk Augsburg	Slow-speed Tandem	*Zeit. des Ver. Deut. Ing.*, Aug. 12/05, p. 1312.
...	Do.	
Belliss & Morcom	High-speed Triple Expansion	*The Engineer*, January 8, 1904, p. 47.
Yates & Thom	...	*The Electrician*, March 17, 1905, p. 886.
M'Intosh & Seymour	Vertical Cross Compound	*The Engineer*, July 14, 1905, p. 27.
Sulzer	Slow-speed Triple Expansion	*The Engineer*, May 25, 1900.
Do.	Do.	Do. do.
Do.	Do.	Do. do.
Kerchove	...	Von den Kerchove. Société Anonyme des Anciens Ateliers de construction van den Kerchove.
Do.	...	
Do.	...	
Allis	...	*Engineering*, September 12, 1902, p. 349. Prof. Barr's Report.
J. Musgrave & Sons	Marine Triple Expansion	*Tr. & Ry. Wrld.*, Dec./03, pp. 559-563.
Westinghouse Co.	...	*Power*, July 1904, p. 424.
Wallsend Slipway and Eng. Co.	Three-cylinder Compound	*Engineering*, April 28, 1905, p. 539.
Allis	Vertical Slow-speed Compound	[1] *Description of the New York Subway*, p. 85; Interborough Rapid Transit Co., 1904.

to calculate the steam consumptions reduced to our standard conditions, the missing details have and assumed.

are from the guarantees of the makers.

The results were divided into three groups of eleven each, corresponding to the smallest, the intermediate, and the largest sizes.

Group I. ranged from 140 K.W. to 400 K.W.
„ II. „ 440 K.W. to 1135 K.W.
„ III. „ 1170 K.W. to 5000 K.W.

The mean steam consumptions at rated full load were as follows:—

Group I.—8·0 Kgs. (17·6 lbs.) per kilowatt-hour.
„ II.—8·0 Kgs. (17·6 lbs.) „ „
„ III.—7·7 Kgs. (17·0 lbs.) „ „

The next step consisted in taking the three lowest results from each group and averaging them, as shown in Table CI.

TABLE CI.

	Group I. 140 K.W. to 400 K.W.		Group II. 440 K.W. to 1135 K.W.		Group III. 1170 K.W. to 5000 K.W.	
	Kgs.	Lbs.	Kgs.	Lbs.	Kgs.	Lbs.
Three lowest results out of eleven	7·2	15·8	6·7	14·7	6·9	15·2
	7·2	15·8	7·3	16·1	7·1	15·6
	7·3	16·1	7·3	16·1	7·1	15·6
Average of three lowest results	7·2	15·9	7·1	15·6	7·0	15·5

As these nine results are obtained from engines of seven different manufacturers in four different countries, they may fairly be taken as indicative of the possibilities of piston engines as a type. One point to note is, that practically as good economy in steam consumption is obtainable on small sizes as on large sizes.

The results for the thirty-three cases set forth in Table C. have been plotted in Fig. 250. In this figure the test results are indicated by circles, and the results, reduced to our standard conditions, have been indicated by crosses. In Fig. 251 the latter are reproduced, together with curves L and III. of Fig. 249.

With these groups of data available, the next question that arises relates to the curve to be adopted as representative of the

average steam consumption of the best types of modern piston engines. We consider that Fig. 251 affords ample evidence that

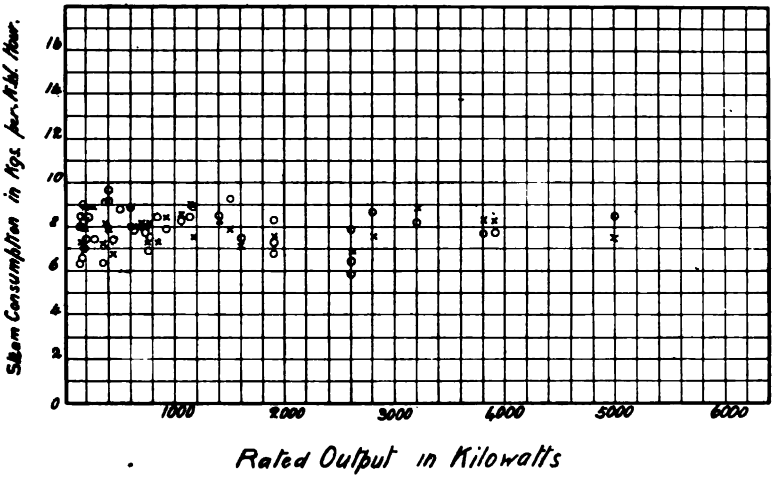


FIG. 250.—Steam Consumption of Piston Engines at Rated Full Load, from published Tests.

O = Test Conditions. X = O reduced to our Standard Conditions.

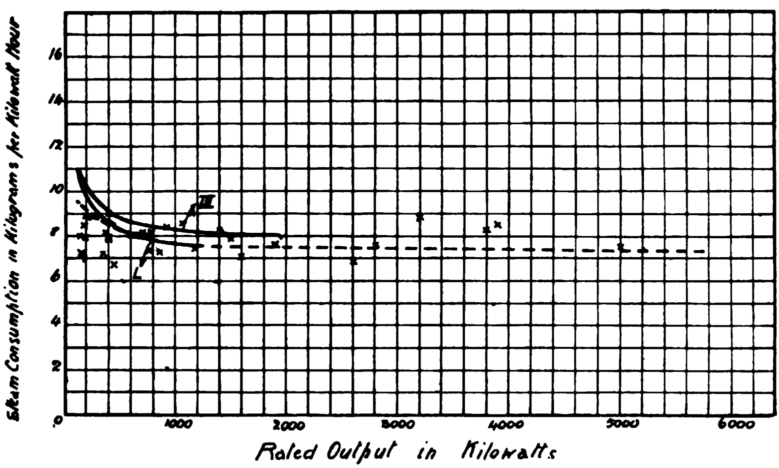


FIG. 251.—Steam Consumptions of Piston Engines at Full Load.

Curves L and III from Fig. 249.
Points X are other published Tests reduced to our "Standard Conditions."

even Lasche's curve (L) hardly does justice to the reciprocating engine, since considerably better results have frequently been ob-

tained, and sometimes under less favourable conditions of pressure, temperature, and vacuum. That curve III. lies so much higher than many of the plotted published results may be partly due to its representing a rough mean instead of the best amongst the guarantees sent us, and also to the necessity, on the part of the manufacturers, to make sufficiently conservative guarantees to leave themselves a margin of safety.

We have finally decided to take as the representative curve for the steam consumption of piston engines, when operated at rated full load, with an absolute admission pressure of 13 kilograms per

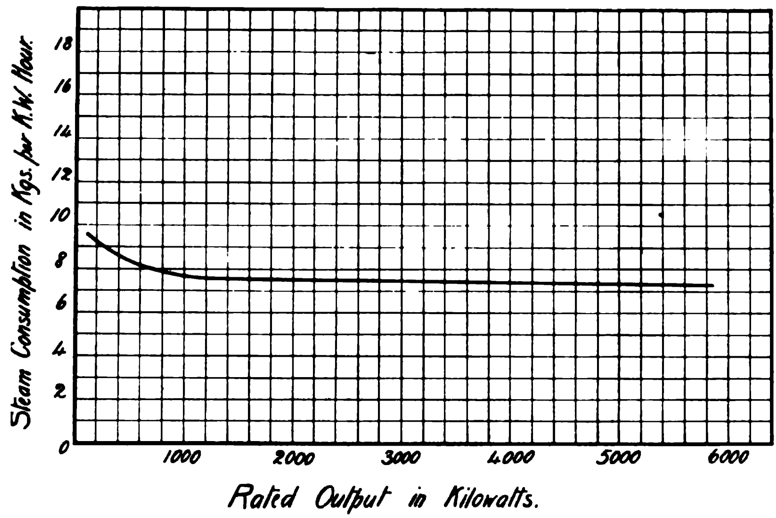


Fig. 252.—Standard Representative Curve for Steam Consumption of Modern Piston Engines at Full Rated Load.

Under the Standard Conditions: Absolute Admission Pressure 13 Kgs. per Sq. Cm., 50° C. Superheat, 86·6 per cent. (26 Ins.) Vacuum. (Derived from Fig. 251.)

square centimetre, 50° C. of superheat and a vacuum of 86·6 per cent. (26 inches), the curve shown dotted in Fig. 251. With regard to this representative curve, it should be noted that Lasche's curve was deduced from full-load tests, run probably with a better vacuum and a greater amount of superheat than those of our standard conditions, the admission pressure being about the same. A curve derived from Lasche's, but with our standard conditions, would lie above curve III. Taking this fact into consideration and also the low positions of some of our plotted results, we have decided that a fairly representative curve for our standard conditions can be obtained by embodying a portion of Lasche's

curve for a range of outputs from 500 kilowatts to 1200 kilowatts. The portion of the curve for the smaller ratings lies somewhat lower than the corresponding portion of Lasche's curve, in consideration of the low steam consumptions often obtained with piston engines within this range of rated outputs. The curve then passes into that of Lasche's up to the limit of the range considered by him, the continuation of the curve beyond this point taking the form of a straight line, very gradually falling as the ratings of output increase. This curve, which is reproduced separately in Fig. 252, will subsequently be taken as a basis for the investigation of

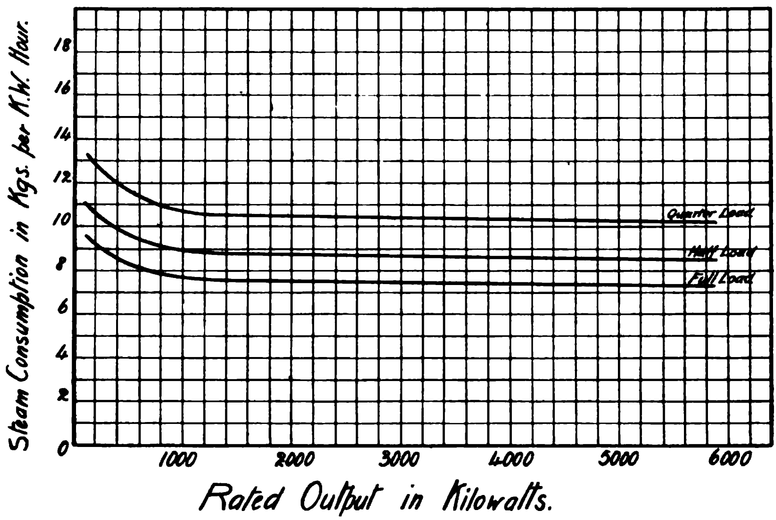


FIG. 253.—Representative Steam Consumptions of Piston Engines. Our Standard Conditions: 13 Kgs., 50° C., 86·6 per cent. (26 Ins.).

the effect on the steam consumption of modern piston engines resulting from variations in the admission pressure, vacuum, and superheat.

Half Load and Quarter Load: Piston Engines.—In order to obtain representative curves for half load and quarter load, we have deduced from an investigation of the curves in Fig. 248, relating to the engines of four English manufacturers, the result that the steam consumption in kilograms per kilowatt-hour at half and quarter loads may be taken at 16 per cent. and 40 per cent. respectively above the values at rated full load. Applying these values to the standard full-load curve of Fig. 252, we have obtained the three curves drawn in Fig. 253,

and shall in subsequent comparisons consider these as representative values for the steam consumption of modern piston engines when operating under the specified conditions of an absolute admission pressure of 13 kilograms per square centimetre, 50° C. of superheat, and a vacuum of 86·6 per cent. (26 inches).

Varying Admission Pressure: Piston Engines.—We have seen in Chapter IV. that very little difference is effected in the steam economy of the Parsons type of steam turbine by variations of the admission pressure, and we believe that it may

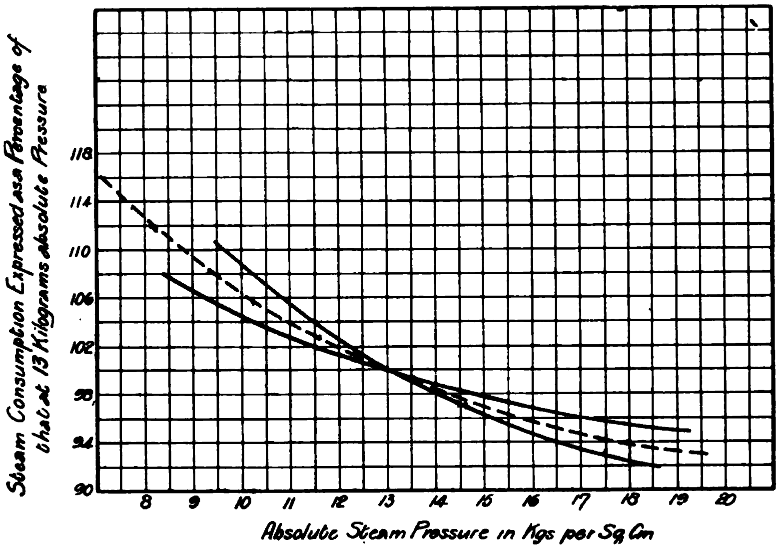


FIG. 254.—Variations in Steam Consumption with Varying Pressure. Piston Engines with 50° C. Superheat, 86·6 per cent. Vacuum.

be correctly stated that most of the types of steam turbine, while more dependent upon the admission pressure than the Parsons type, are much less dependent upon the value of this factor than are most piston steam engines.

To investigate this point of the dependency of the steam consumption of the modern piston engine on the admission pressure, we have obtained from two leading English manufacturers of piston engines their estimates of the relation between steam economy and admission pressure. Representing as 100 the steam consumption under our standard conditions of an absolute admission pressure of 13 kilograms per square centimetre, a

superheat of 50° C., and a vacuum of 86·6 per cent., then for the same number of degrees of superheat and the same vacuum the figures representative of the consumption for other admission pressures may be obtained from Fig. 254 for the piston engines of these two manufacturers. We propose to take the dotted line as representative for piston engines in general.

Varying Superheat: Piston Engines.—As to the effect of superheat on piston engines, we have compared useful data from seven firms. This data has been embodied in the curves of

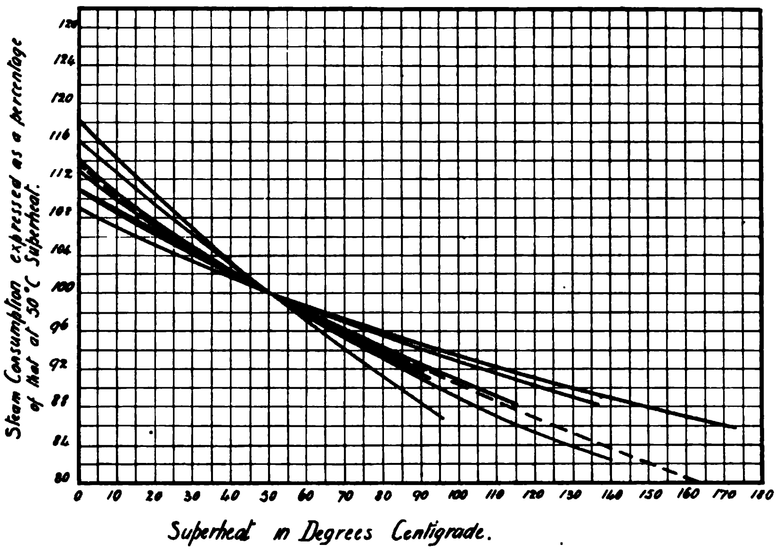


FIG. 255.—Piston Engines: Variations in Steam Consumption at Full Load, with Varying Superheats.

13 Kgs. per Sq. Cm. Absolute, 86·6 per cent. Vacuum.

Fig. 255, and the dotted-line curve will be taken as representative of the effect of superheat on the steam consumption of piston engines for our standard conditions of admission pressure and vacuum.

The mean is replotted separately in Fig. 256, and it is again plotted in Fig. 257, in terms of the average percentage decrease in steam consumption per 1° Cent. of superheat above the temperature of saturated steam. It should be noticed that the percentage gain by superheat is well sustained up to very high superheats, and hence piston engine manufacturers have a great incentive to adopt for a given pressure as high a steam tempera-

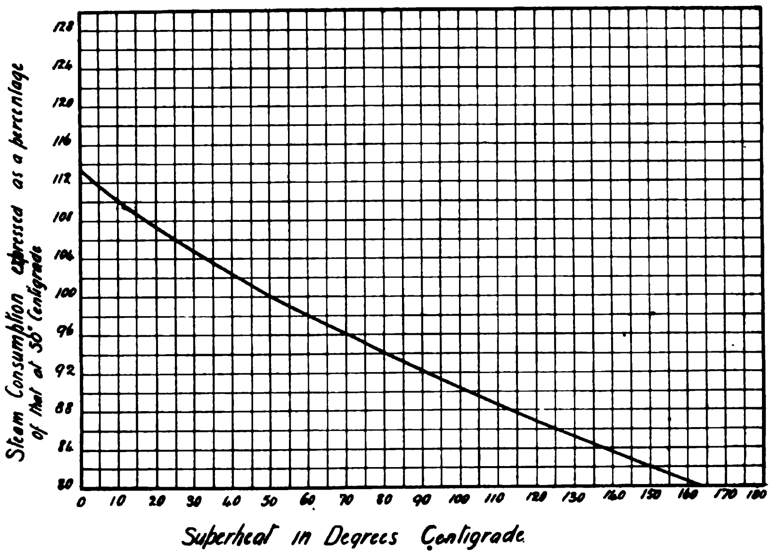


Fig. 256.—Effect of Superheat on Steam Consumption of Piston Engines. (Derived from dotted Curve, Fig. 255.)

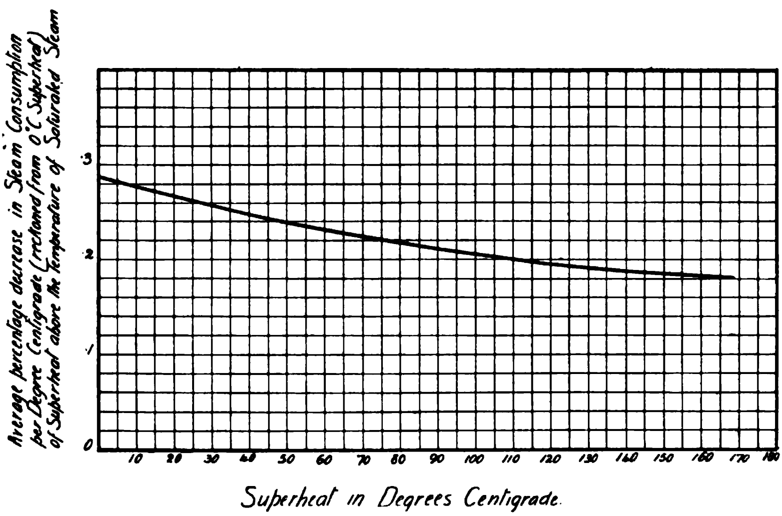


Fig. 257.—Percentage Decrease in Steam Consumption (Full Load) per Degree C. Increase of Superheat: Piston Engines.

Under our Standard Conditions: 13 Kgs. per Sq. Cm. Absolute Pressure and 86·6 per cent. (26 Ins.) Vacuum.

ture as other considerations, such as those relating to lubrication, permit.

Varying Vacuum: Piston Engines.—We have next to consider the effect of the degree of vacuum on the steam consumption of the piston engine. There is admittedly less gain in the economy of the piston engine obtainable by improvement in the vacuum than for the steam turbine. A further limitation relates to the design of the low-pressure cylinder and piston, which attain abnormal dimensions when proportioned for a high vacuum. In the neighbourhood of the standard vacuum which we have adopted (86·6 per cent., *i.e.*, 66 centimetres, or 26 inches), the improvement in the steam economy of the piston engine with higher vacua may be taken at about 0·8 per cent. per centimetre improvement in vacuum (2 per cent. per inch of vacuum), or about 0·6 per cent. per 1 per cent. improvement in steam consumption for the range from 26 inches to 28 inches (*i.e.*, 86·7 per cent. vacuum to 93·3 per cent. vacuum). In a great many cases the gain is even smaller than this. Thus Weiss,[1] in his experiments, arrived at the formula—

$$\left.\begin{array}{l}\text{Decrease in steam consump-}\\ \quad\text{tion in per cent. per cm.}\\ \quad\text{increase of vacuum}\end{array}\right\} = \frac{3{\cdot}5}{\text{Abs. pressure in Kgs. per sq. cm.}}$$

This works out at about 0·3 per cent. per centimetre for normal cases. The formula applies to compound and triple-expansion engines. For single-cylinder machines the decrease is smaller still, namely—

$$\frac{1{\cdot}7}{\text{Abs. pressure in Kgs. per sq. cm.}}.$$

These results tend to show that we certainly do not underestimate the influence of improved vacuum on the economy of piston engines if we allow a 2 per cent. decrease in steam consumption in going from 86·6 per cent. vacuum to 90 per cent., and a further 2 per cent. in going from 90 per cent. to 93·3 per cent. As already mentioned, the reason for this small decrease, compared with the theoretical decrease, lies in the impossibility, or at any rate the impracticability, of so constructing the low-pressure cylinders as to conform to the conditions entailed by the low vacuum.

[1] *Die Turbine*, July 1905, article by A. Lapouche, entitled "Einfluss des Vakuums auf den Dampfverbrauch der Dampfturbinen."

The losses due to cylinder condensation play a very important rôle, and the cost and weight of the whole set is increased considerably in striving to make the best use of so very good vacua.

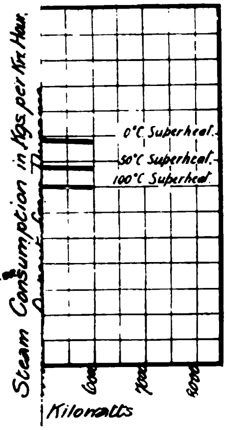
Now, with this data for the effect of admission pressure, superheat, and vacuum on the steam consumption, we can, from our mean curve (Fig. 252) for piston engines, designed for our standard conditions, obtain a series of curves of full-load economy of piston engines designed for other conditions. Such a series of full-load steam-consumption curves is given in Figs. 258 to 269.

[To face p. 388.

Cm. Abs.
In. Abs.

7 Kgs. per Sq. Cm. Abs.
100 Lbs. per Sq. In. Abs.

Vacuum 86·6 *per cent.*
,, 26 *ins.*



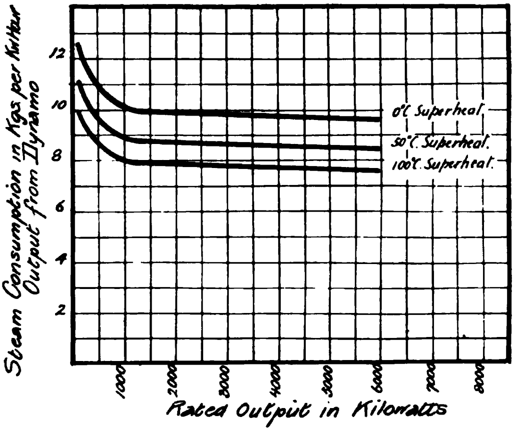
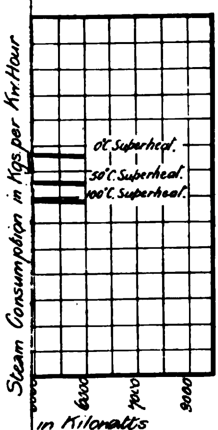


FIG. 261.

Vacuum 90 *per cent.*
,, 27 *ins.*



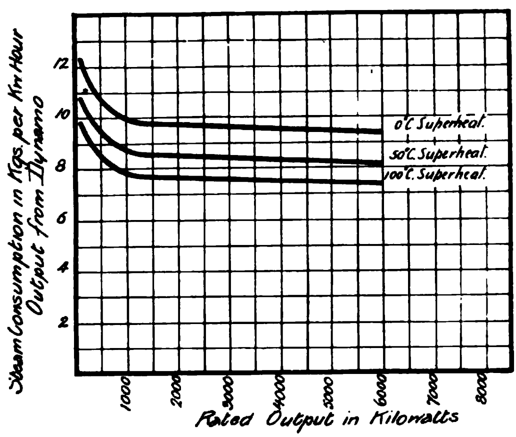
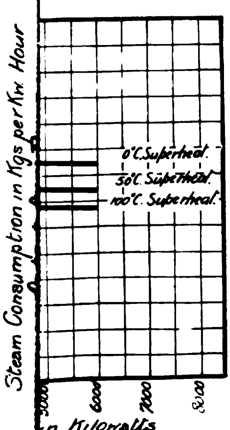


FIG. 265.

Vacuum 93·3 *per cent.*
,, 28 *ins.*



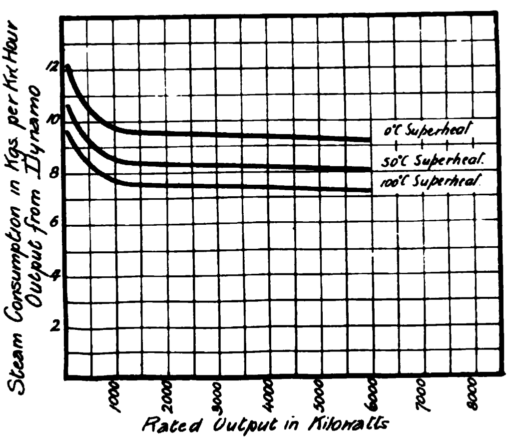


FIG. 269.

to the four figures in the same row.

CHAPTER XVI

MEAN REPRESENTATIVE RESULTS FOR STEAM TURBINES, AND COMPARISON WITH RESULTS FOR PISTON ENGINES

IN Chapters III. to XII. we have given data of the steam consumption of various types of steam turbines. Of these types, the results of such a large number of tests on the de Laval and Parsons type are available, that it is practicable to embody the conclusion in curves.[1] When reduced to the standards of reference which we have chosen for this purpose, viz., an admission pressure of 13 absolute metric atmospheres, 86·6 per cent. vacuum, and 50 degrees Cent. of superheat, we obtain for full, half, and quarter loads respectively the results shown in Figs. 270, 271, and 272.

In each of these three figures we have drawn a dotted-line curve of what we consider to give, for practical purposes, a fair representation of the entire set of results. These dotted curves are reproduced in the three curves of Fig. 273, and are to be taken as representative, at full, half, and quarter load respectively, of the steam consumption of steam turbines in general, for the present state of development. The corresponding results for good piston engine practice are given in the three curves of Fig. 274, which are identical with those in Fig. 253 of the previous chapter. In Figs. 275, 276, and 277, relating respectively to full load, half load, and quarter load, there have been brought together the curves for steam turbines and piston engines, corresponding to the standard pressure, temperature, and vacuum adopted in this treatise.

It is exceedingly difficult to make such a comparison, owing to the individual characteristics of the various types, not only

[1] A curve has also been added setting forth the values guaranteed for the Elektra type.

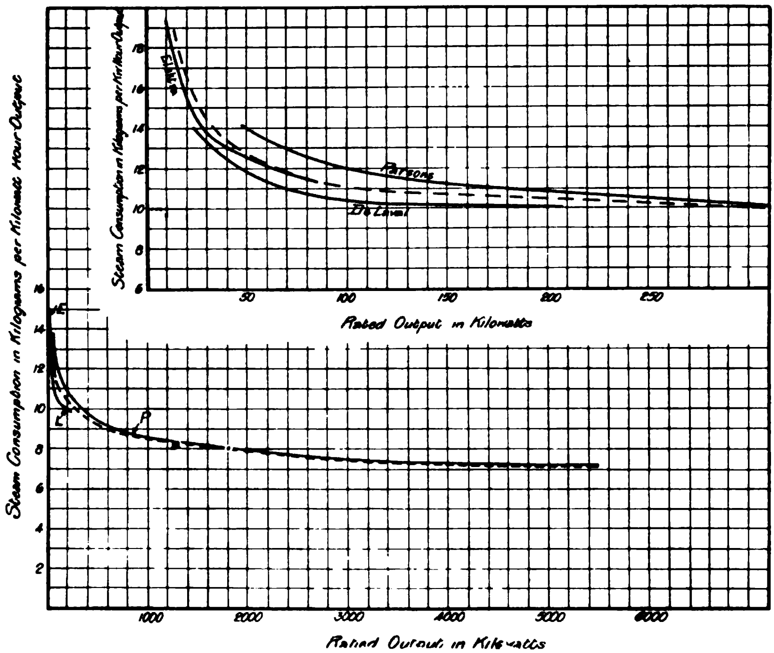


FIG. 270.—Rated Full Load.

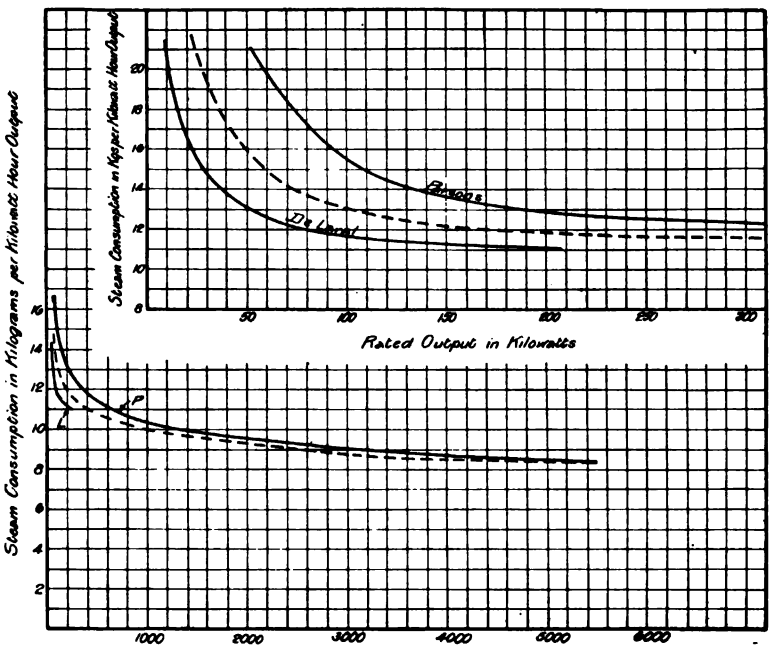


FIG. 271.—Half Load.

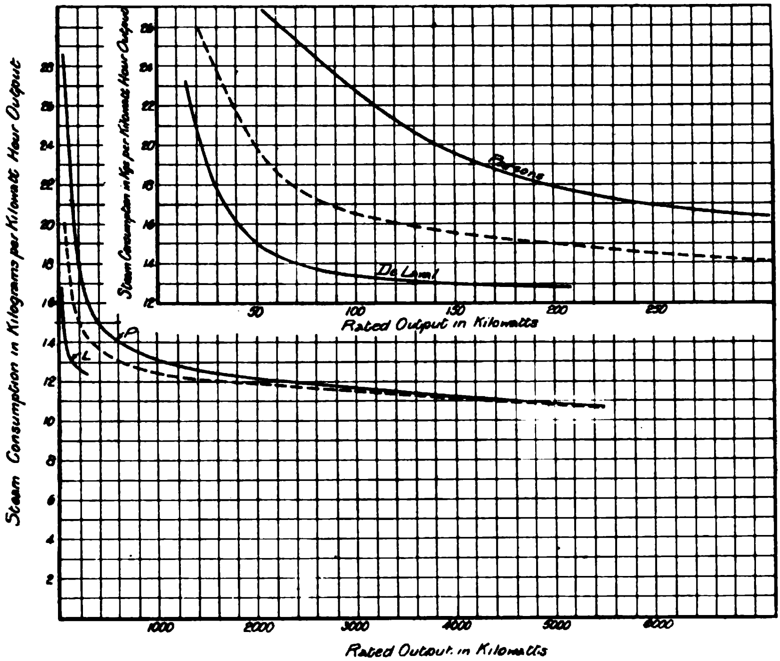


Fig. 272.—Quarter Load.

Figs. 270, 271, and 272.—Steam Consumption of Steam Turbines.

13 Kgs. per Sq. Cm. Absolute, 50° C. Superheat, 86·6 per cent. Vacuum.
P = Parsons, L = de Laval, E = Elektra.

of the reciprocating engines, but also of steam turbines. Nevertheless, our conclusions have only been deduced after a very thorough investigation, and we consider that they give as good a general comparison between the two great classes of steam engines as can at present be arrived at.

Before we develop for steam turbines a series of curves, similar to those of Figs. 258 to 269 representing piston engines, we must consider the influence of admission pressure, superheat, and vacuum on the steam consumption of steam turbines. The question has already been considered in the previous chapters for some of the types of turbines.

For the purpose of comparison between piston engines and turbines as two classes of steam engine, as regards their respective steam economies, we have decided to confine ourselves to the Parsons steam turbine, since the data and test results on this type are far more exhaustive than those on any other; also the

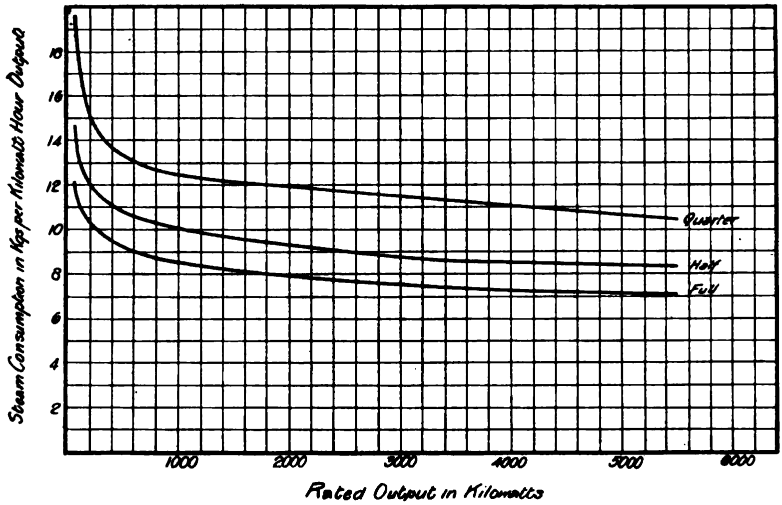


FIG. 273.—Turbines.

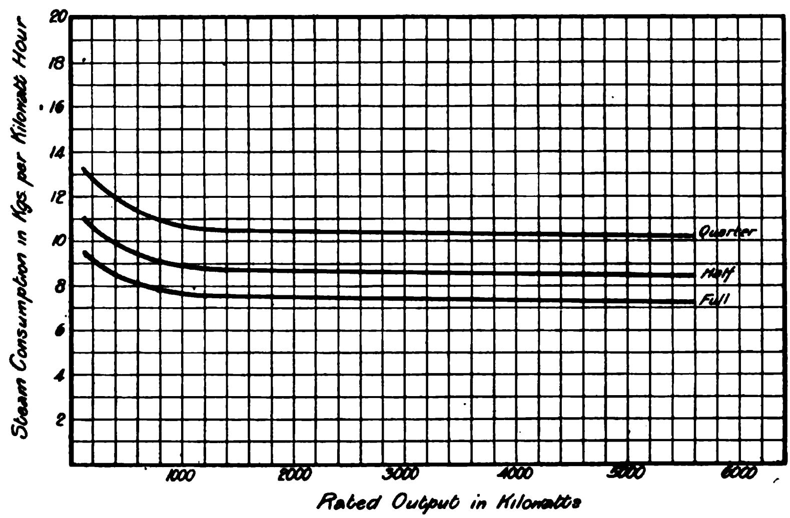


FIG. 274.—Modern Piston Engines.

FIGS. 273 and 274.—Representative Steam Consumptions for Turbines and Modern Piston Engines.

18 Kgs. per Sq. Cm. Absolute, 50° C. Superheat, 86·6 per cent. Vacuum.

range of capacity over which tests have been made is greater. From these and other considerations, this type of steam turbine

has been chosen as most suitable for the purpose of comparison with piston engines as a class.

The economy of the Parsons type of turbine is influenced but very slightly by variations in steam admission pressure ; so slightly, in fact, as to render a diagram representing this influence of very little value.

In deriving curves of steam consumption for other than our standard conditions of pressure, superheat, and vacuum, we have proceeded as follows :—

The effect of varying admission pressure is taken in accordance with the conclusions at which we arrived as the result of our investigation of the Parsons type of steam turbine.

From these values the following rate of variation was estimated and assumed :—

Decreasing the absolute admission pressure from 16 kilograms to 13 kilograms per square centimetre increases the steam consumption by 1 per cent.

Decreasing the absolute admission pressure from 13 kilograms to 10 kilograms per square centimetre increases the steam consumption by 2 per cent.

Decreasing the absolute admission pressure from 10 kilograms to 7 kilograms per square centimetre increases the steam consumption by 4 per cent.

The influence of superheat on the steam consumption of the Parsons type of turbine is shown in Fig. 278 (reproduced from Fig. 118).

Fig. 279 shows the effect of vacuum on steam consumption of the Parsons turbine, and is derived from Fig. 110.

From this data we have derived the sets of curves in Figs. 280 to 291 inclusive.

Comparisons: Piston Engines and Steam Turbines.—In Figs. 292 to 299 have been brought together, for the purpose of comparison, the full-load steam-consumption curves for piston engines and steam turbines, derived from the sets of curves in Figs. 258 to 269 and Figs. 280 to 291. In the set of curves in Figs. 292 to 295 the steam consumptions have been considered only under the extreme conditions considered, namely, absolute admission pressures of 16 kilograms and 7 kilograms per square centimetre, vacuum of 93·3 per cent. and 86·6 per cent., with superheats of 50° C. (Figs. 292 to 295) and of 100° C. (Figs. 296 to 299).

Before proceeding to discuss or draw any conclusions from

this set of curves, it would be well to describe briefly the curves represented in Figs. 300, 301, and 302. Throughout, the com-

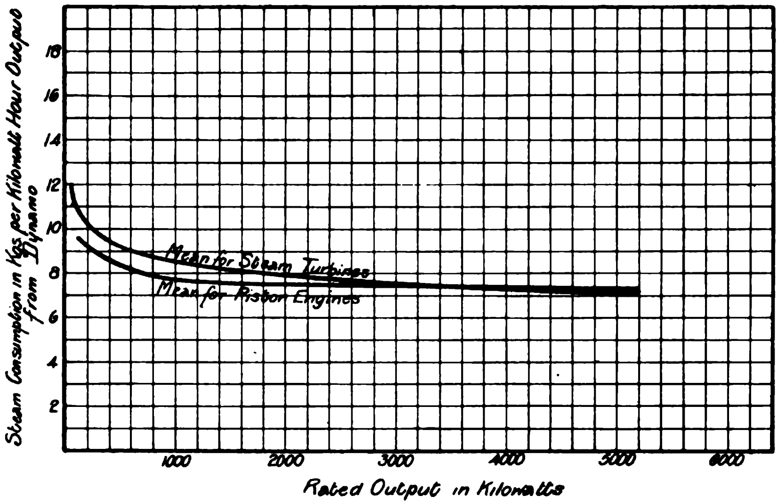


FIG. 275.—Rated Full Load.

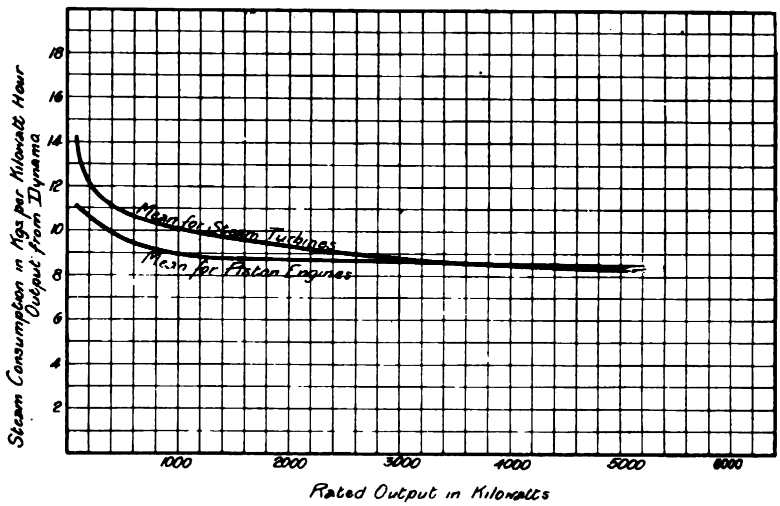


FIG. 276.—Half Load.

parisons have been drawn between the full-load steam consumptions only of piston engines and steam turbines. In Figs. 300, 301,

and 302, however, an attempt has been made to represent in diagrammatic form the increase in steam consumption with the decrease of load. The abscissæ indicate the load, the ordinates representing the steam consumption as a percentage of that at fully-rated load.

Fig. 300 is confined to modern piston engines. There are eight curves in all, representing the consumptions of nine different engines, ranging in capacity from 30 kilowatt to 1600 kilowatt. In addition to the actual consumption curves, two limit-curves

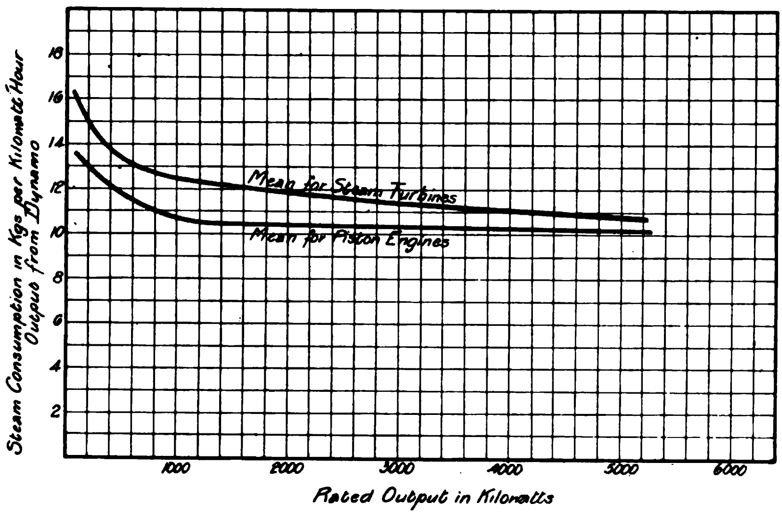


FIG. 277.—Quarter Load.

FIGS. 275, 276, and 277.—Comparison of Representative Steam Consumptions, Turbines and Piston Engines.

Our Standard Conditions: 13 Kgs. per Sq. Cm. Absolute, 50° C., 86·6 per cent. (26 Ins.).

have been drawn, fairly representing what may generally be considered as the highest and lowest steam consumptions at various loads.

A few words concerning curve IX of Fig. 300 will not be out of place at this point. Curve IX is for a 1600 kilowatt engine by M'Intosh & Seymour, and it will be noticed from the shape of the curve that the minimum steam consumption occurs when the engine is running at about ⅝ load.

Fig. 301 contains similar curves for steam consumptions of

steam turbines ranging from 250 kilowatt to 4000 kilowatt output. On account of certain difficulties previously mentioned, only the Parsons type has been considered. In this figure, as in Fig. 300, upper and lower limit-curves have been drawn.

In Fig. 302 the limit-curves of Figs. 300 and 301 have

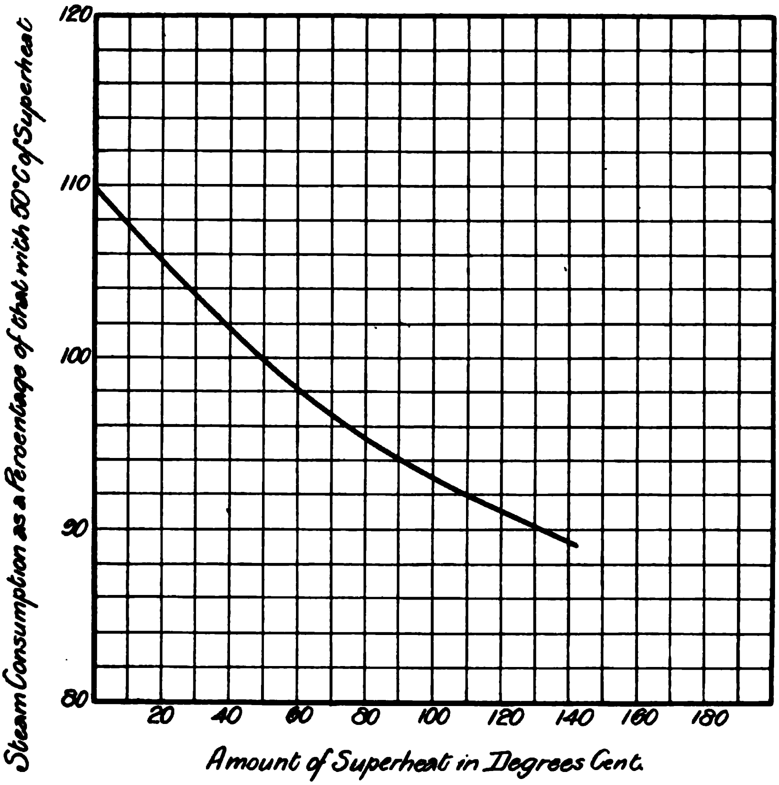


FIG. 278.—Variations in Steam Consumption with Varying Superheat, Parsons Turbines. (From Fig. 118.)

been replotted, the dotted line representing piston engines, the full line steam turbines. The areas enclosed have been shaded with vertical and horizontal lines respectively.

From this diagram it is obvious that there is practically no difference, so far as relates to these sets of tests, as regards the percentage of steam consumption at full load between the two types of steam engines. This diagram is instructive, inasmuch as it indicates graphically within what limits the steam consumption

per Sq. Cm. Abs.
per Sq. In. Abs.

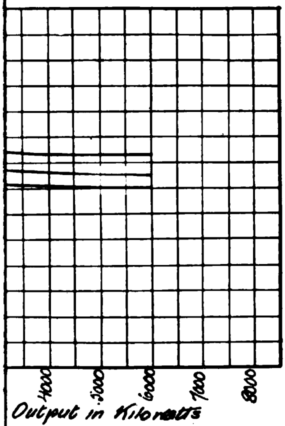


FIG. 282.

7 Kgs. per Sq. Cm. Abs.
100 Lbs. per Sq. In. Abs.

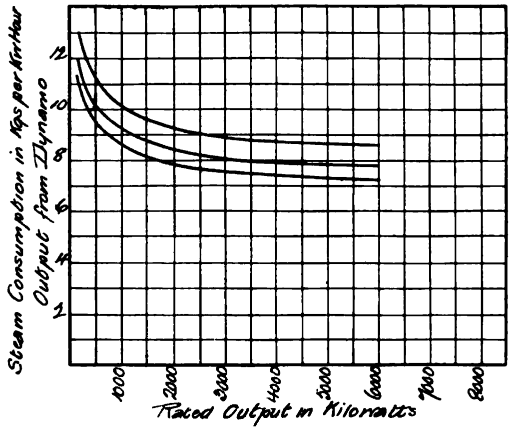


FIG. 283.

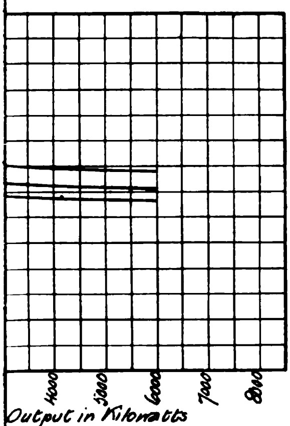


FIG. 286.

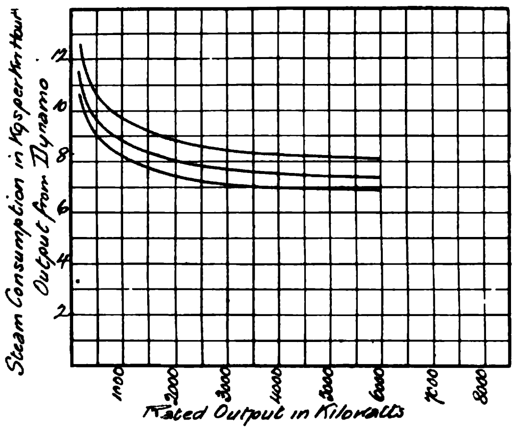


FIG. 287.

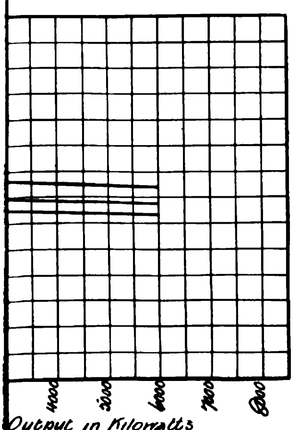


FIG. 290.

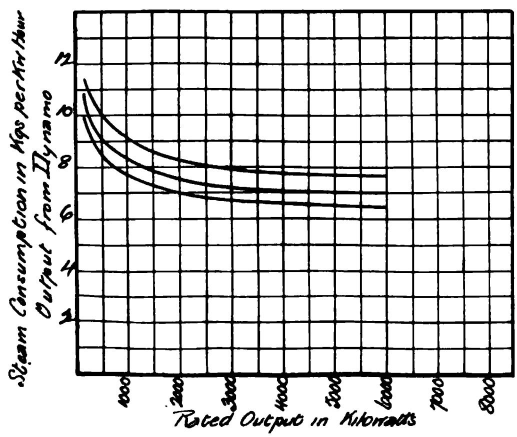


FIG. 291.

rbines.

e left applies to the four figures in the same row.

at various loads, expressed as a percentage of the full-load consumption, can be expected to lie.

Returning now to Figs. 292 to 299, it should be noticed that, under the conditions of a good vacuum and a low admission pressure, the steam turbine has certainly an advantage over

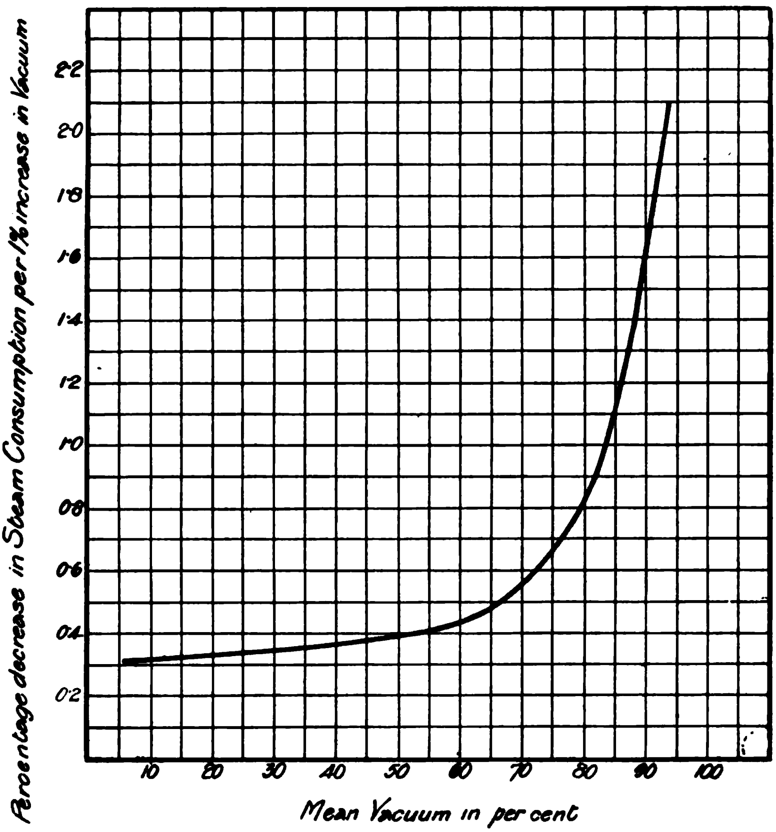


FIG. 279.—Percentage Decrease in Full Load Steam Comsumption of Parsons Turbine per 1 per cent. Increase in Vacuum. (From Fig. 110.)

the piston engine. Generally speaking, the highest steam economies have been obtained with piston engines, though, at the same time, a point very little inferior has been reached by turbines when working under favourable conditions. As can be seen from the set of figures Nos. 292 to 299, and also by reference to figures previously given, it is a notable fact that the employment of superheat has a considerably greater influence on

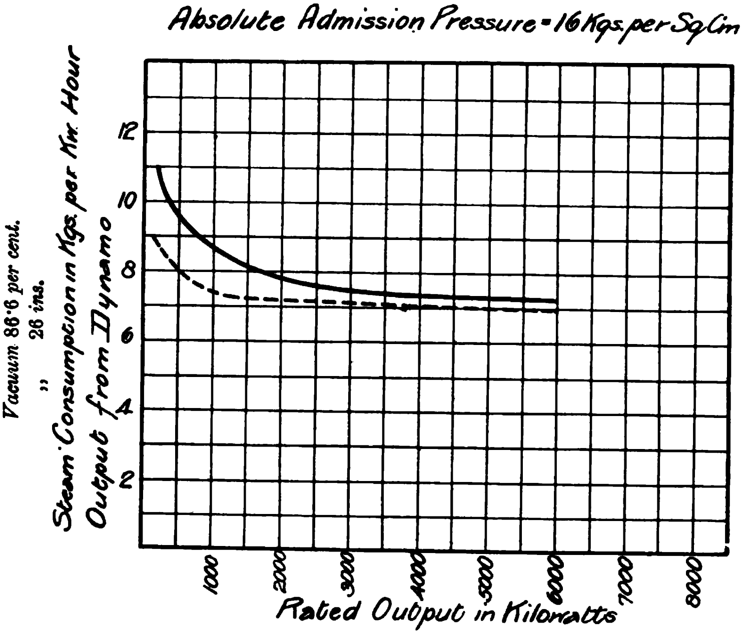


FIG. 292.

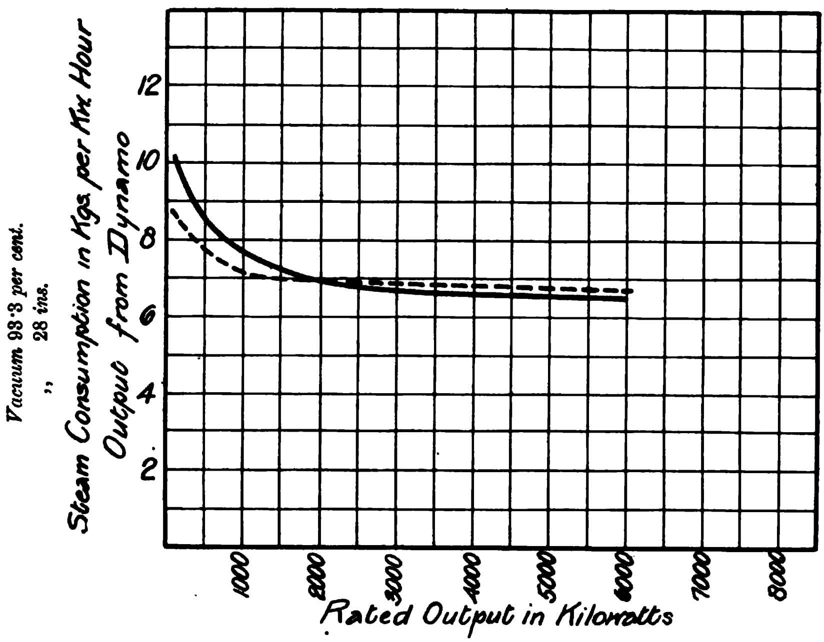


FIG. 294.

FIGS. 292 to 295.—Comparison of Full Load
Piston Engines: Dotted Lines.
(Derived from Figs. 258

Vacuum 86·6 per cent.
„ 26 ins.

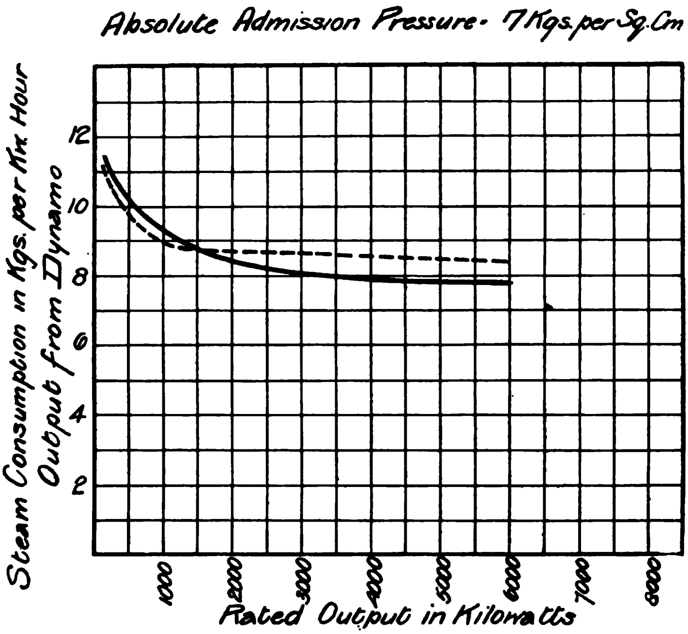


FIG. 293.

Vacuum 93·3 per cent.
„ 28 ins.

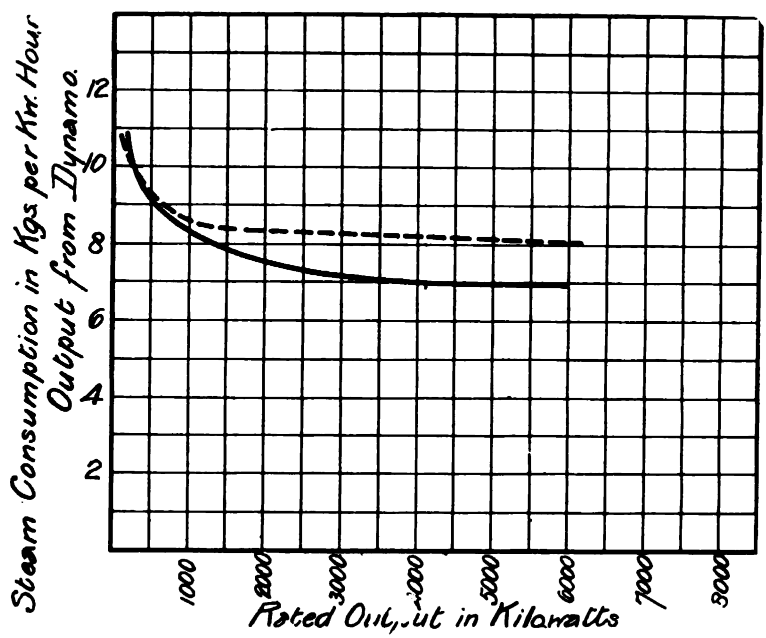


FIG. 295.

Steam Consumptions—all with 50° C. Superheat.
Steam Turbines : Full Lines.
to 269, and 280 to 291.)

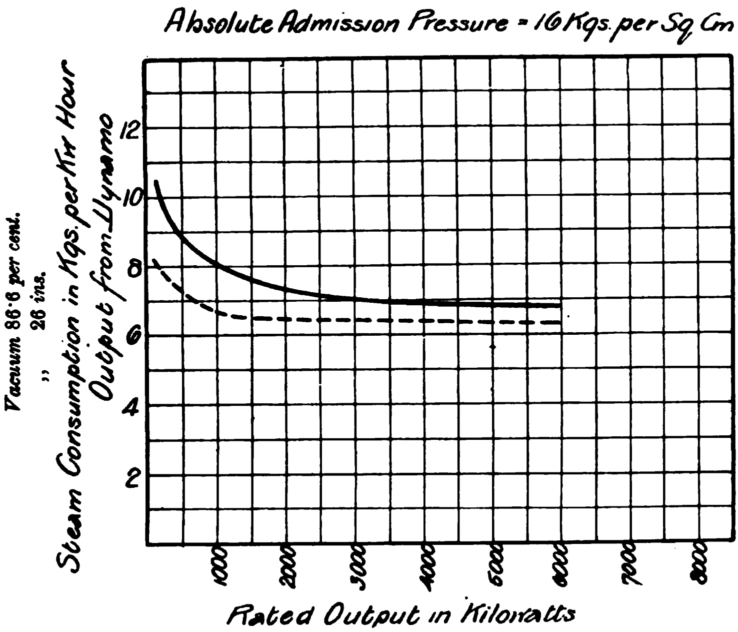


FIG. 296.

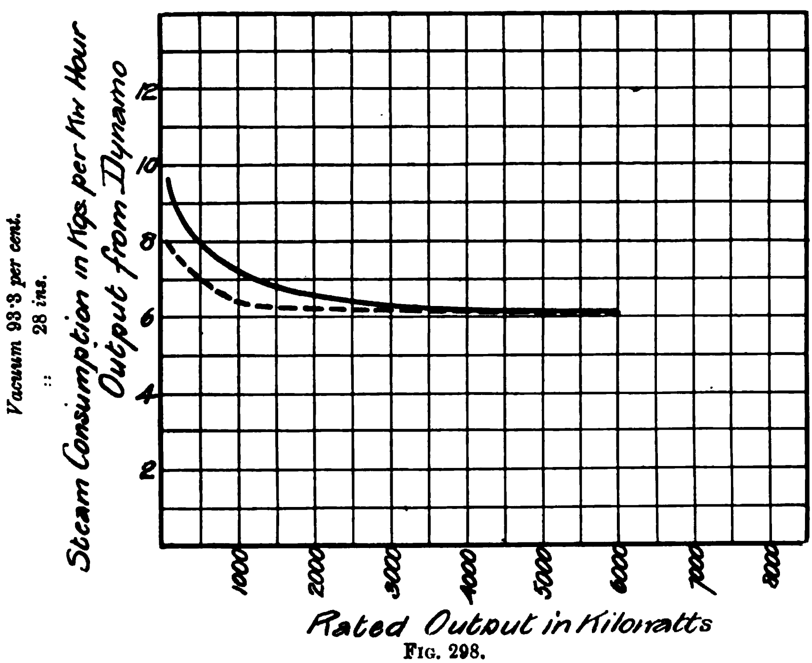


FIG. 298.

FIGS. 296 to 299.—Comparison of Full Load
Piston Engines: Dotted Lines.
(These Curves derived from Figs. 258

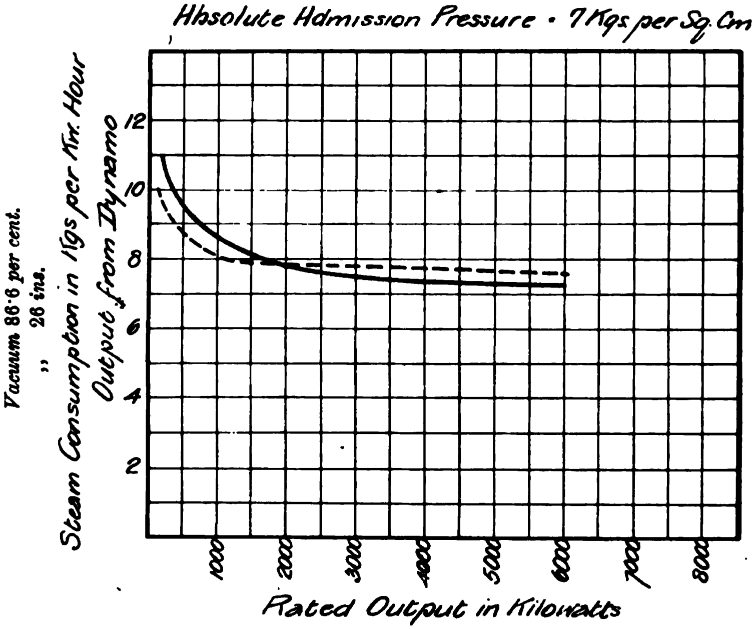


FIG. 297.

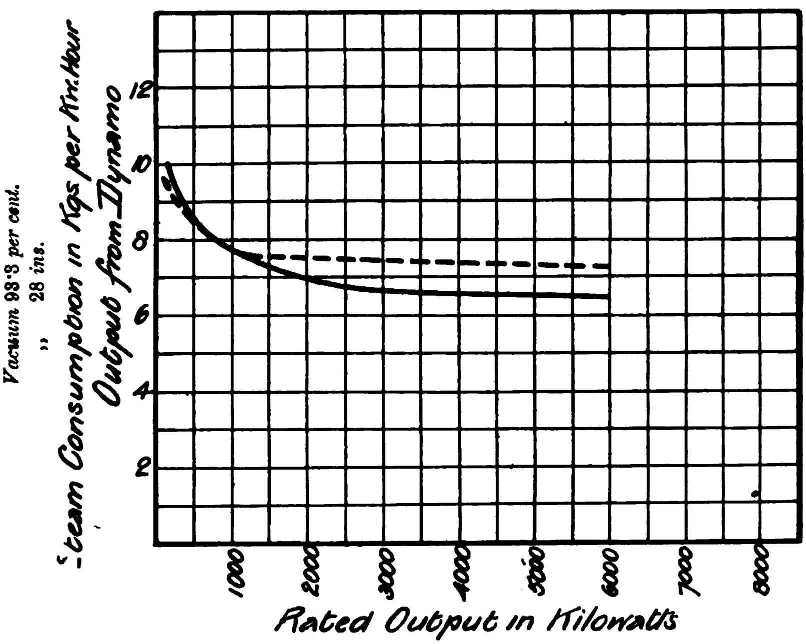


FIG. 299.

Steam Consumptions—all with 100° C. Superheat.
Steam Turbines: Full Lines.
to 269, and 280 to 291.)

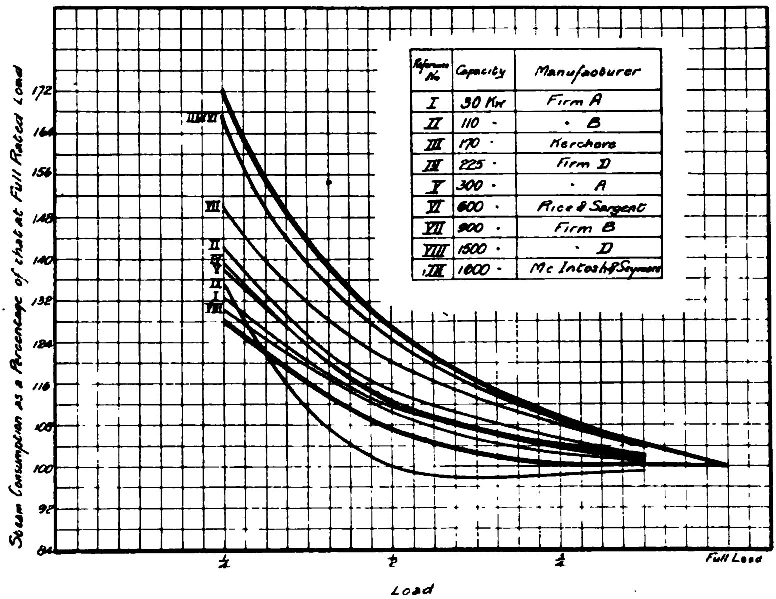


FIG. 300.—Modern Piston Engines.

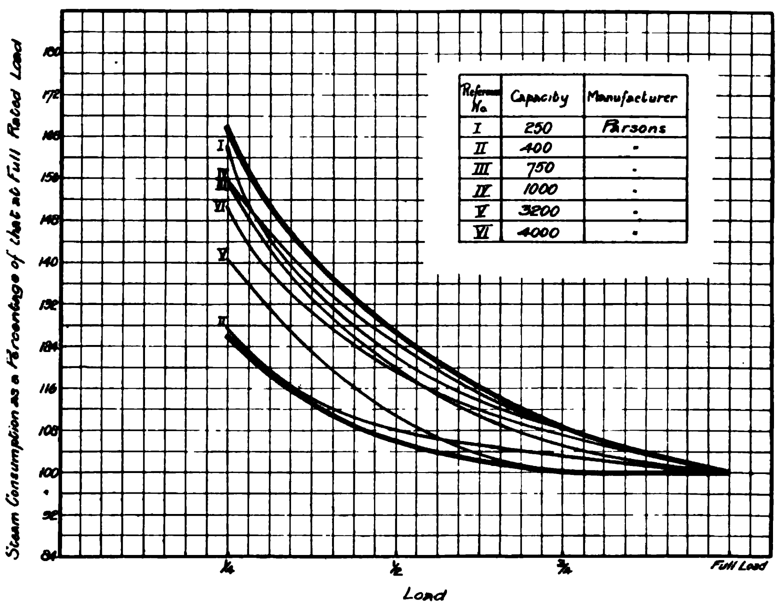


FIG. 301.—Parsons Turbines.

FIGS. 300 and 301.—Steam Consumption at Various Loads for Modern Piston Engines and Parsons Turbines as a Percentage of the Full-Load Consumption.

the steam consumption in the case of piston engines than in that of steam turbines. With vacuum, however, the reverse is the case, the steam economy of the turbine being more beneficially affected by a high vacuum than is the economy of the piston engine.

The forecasting of the future as regards the steam engine, whether of the turbine or reciprocating type, is by no means an easy matter; but one thing is certain, that their relative positions,

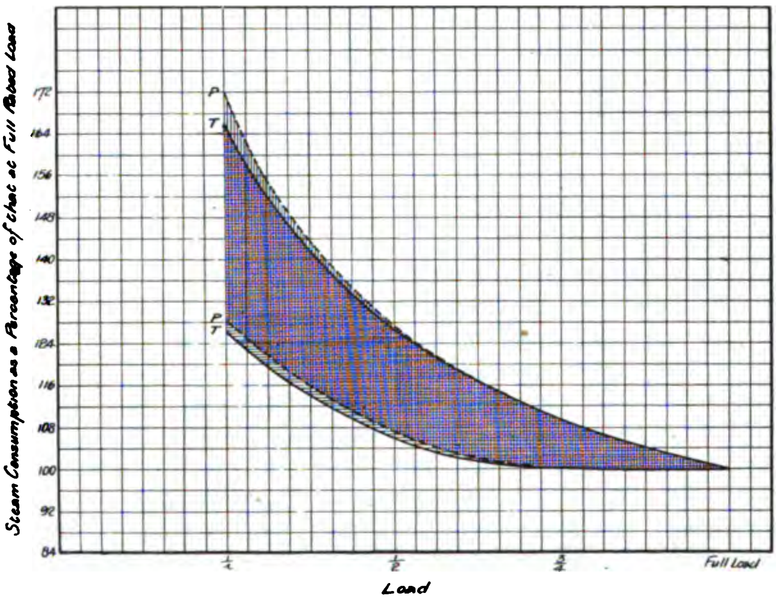


FIG. 302.—Figs. 300 and 301 superimposed.

Piston Engines : Dotted Line and Vertical Shading.
Parsons Turbines : Full Line and Horizontal Shading.

so far as relates to steam consumption, will in the future depend to a very large extent upon the amount to which their above-named especial characteristics are developed and utilised.

The peculiar characteristic of the steam turbine, in being but slightly dependent upon the admission pressure, undoubtedly opens a path for the future deviating from that along which the development of the piston engine will advance. The probable tendency in future designs of steam turbine, for large sizes at any rate, will be to reduce the admission pressure, and therefore the absolute temperature, thus permitting of a greater range of superheat, and removing to some extent the difficulties now

encountered arising from dealing with high temperatures. In the case of the piston engine, whose steam economy is so greatly affected by the admission pressure, the amount of superheat used is limited, on account of the very high temperatures to be dealt with, owing to the high admission pressure.

On the grounds of the utilisation of high vacuum, there are certain obstacles in the way of the development of the steam turbine, consequent on the necessity of more perfect condensing plant. The initial outlay would thus be considerably increased, though there doubtless will follow a considerable advancement in the design of condensers, both as regards efficiency and cost.

So far, these remarks have related only to steam economy, though for an absolute comparison there are, of course, many other points which call for consideration. An exhaustive investigation from this point of view will not be attempted, but there is the question of oil economy, which affects the cases both of piston engines and steam turbines, and is worthy of mention at this juncture. In districts where the cost of coal is 12s. per ton, the cost of oil will generally amount to some 8 per cent. of the cost of coal in the case of good modern piston engines. It is claimed that for the operation of steam turbines the outlay for oil will be reduced to an almost negligible amount (0·5 per cent. to 2 per cent.). If we take it at 3 per cent. for a district where coal costs 12s. per ton, there remains a 5 per cent. advantage for the steam turbine as far as relates to the combined outlay for coal and oil. Hence the steam turbine can afford to have an inferiority of 5 per cent. in steam consumption.

It is too early as yet to attempt to arrive at any useful conclusions as to the relative rates of depreciation of the two types of engine.

Figs. 292 to 299 give a comparison between piston engines and steam turbines as regards their respective steam consumptions, but regarding the comparison from another standpoint, namely, that of commercial efficiency, a series of curves has been plotted in Figs. 303 to 310. In the first place, a definition of the precise meaning of this term, 'commercial efficiency,' as used here, should be given.

Taking into consideration the absolute pressure with the corresponding saturation temperature, and also the amount of superheat used, the number of heat units per kilogram of steam required was calculated. Taking the value of the steam consumed

for a certain output (obtained from curves of Figs. 292 to 299) from our previous calculation of the number of heat units per kilogram of steam, we can obtain the total number of heat units required for that particular output. Having reduced this value to work units, such as kilowatt-hours, the commercial efficiency in per cent. can be obtained, and takes the form of the expression—

$$\frac{\text{Output in kilowatt-hours} \times 100}{\text{Number of kilowatt-hours communicated to the feed water}}.$$

The value of this expression gives us the commercial efficiency in percentage of the particular output considered. By these means the commercial efficiency curves of Figs. 303 to 310, both for piston engines (dotted lines) and steam turbines (full lines), have been plotted.

In these calculations, of course, no question of boiler and furnace efficiencies have been dealt with, there being no reason why these should differ in any respect in the cases either of piston engines or of steam turbines, further than the consideration that in the turbine the steam nowhere comes into contact with oil, and may thus be returned to the boiler more free from impurities, the boiler consequently being more readily maintained in a condition permitting of high efficiency.

This set of curves (Figs. 303 to 310) perhaps bring out more clearly the distinctive characteristics and properties of the two types of steam engine. By an examination of the commercial efficiency curves, we can appreciate the relative effects of admission pressure, vacuum, and superheat. As shown before by the steam-consumption curves, we can see that as regards increase of admission pressure the economy and the consequent efficiency is more benefited in the case of the piston engine, the improvement being scarcely appreciable with steam turbines. With superheat, also, the commercial efficiency of piston engines is improved to a greater extent than is that of the steam turbine. With vacuum, however, the results of improving this condition are reversed, it having a much more beneficial effect with steam turbines than in the case of piston engines.

Still another comparison has been drawn up in Figs. 311 to 318. These curves have been plotted in order to show how the commercial efficiencies of piston engines and steam turbines improve with the increase of admission pressure under various conditions of superheat and vacuum. The axis of abscissæ of each curve is scaled to represent the absolute admission pressure

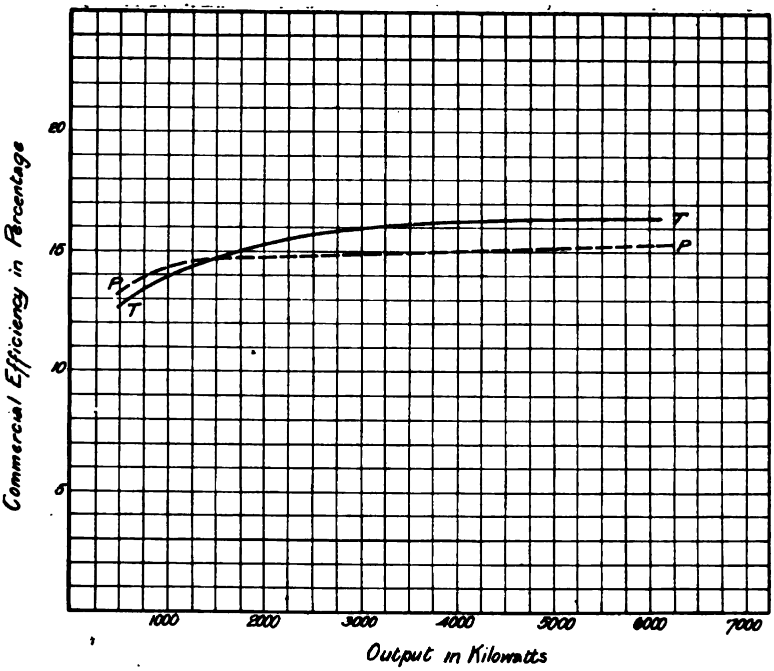


FIG. 303.—7 Kgs. Abs.; 50° C.; 86·6 per cent.
100 Lbs. Abs.; 90° F.; 26 Ins. (From Fig. 293.)

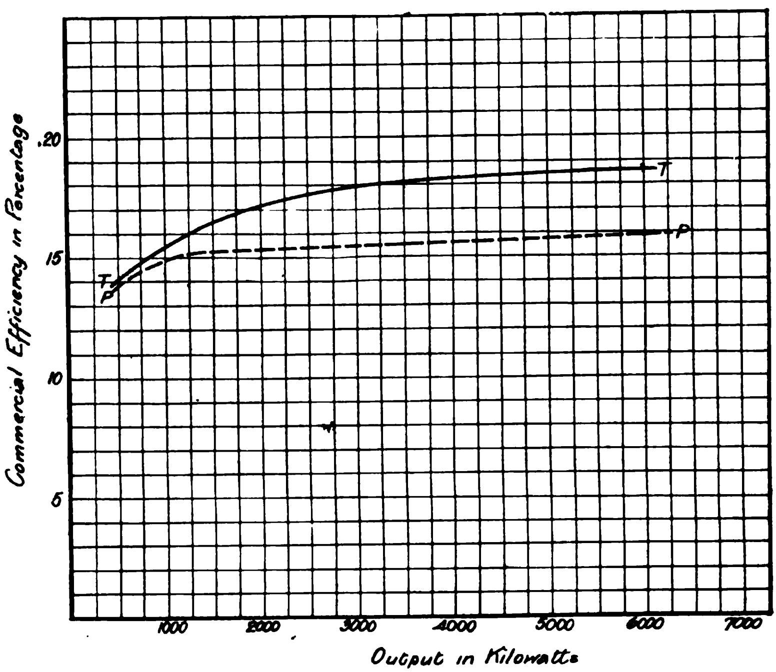


FIG. 305.—7 Kgs. Abs.; 50° C.; 93·3 per cent.
100 Lbs. Abs.; 90° F.; 28 Ins. (From Fig. 295.)

FIGS. 303 to 306.—Comparisons of Commercial Efficiencies at
At two Admission Pressures and two

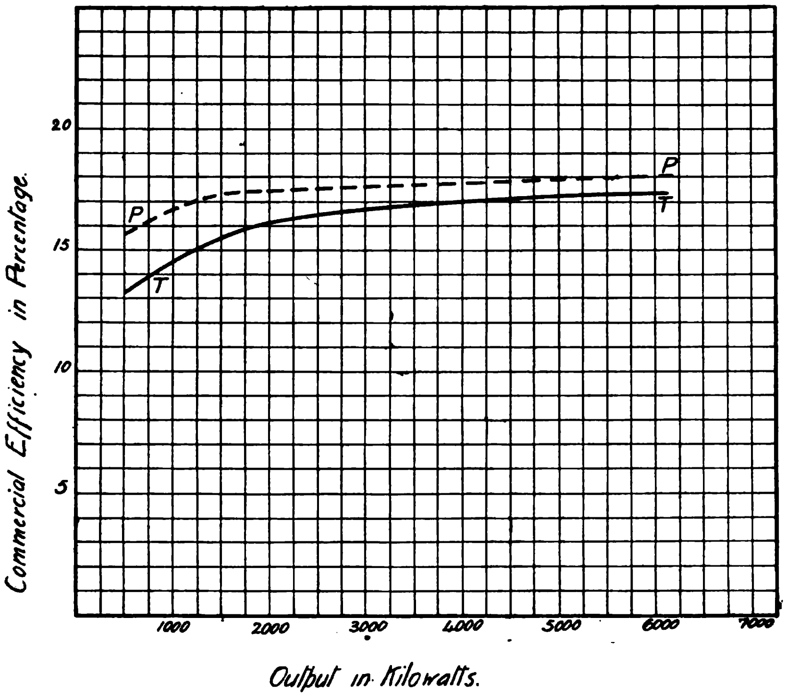


FIG. 304.—16 Kgs. Abs.; 50° C.; 86·6 per cent.
225 Lbs. Abs.; 90° F.; 26 Ins. (From Fig. 292.)

FIG. 306.—16 Kgs. Abs.; 50° C.; 93·3 per cent.
225 Lbs. Abs.; 90° F.; 28 ins. (From Fig. 294.)

Full Load of Piston Engines—(P)—and Steam Turbines—(T)—(Parsons).
Exhaust Pressures. Superheat 50° C. in all.

Fig. 307.—7 Kgs. Abs.; 100° C.; 86·6 per cent.
100 Lbs. Abs.; 180° F.; 26 Ins. (From Fig. 297.)

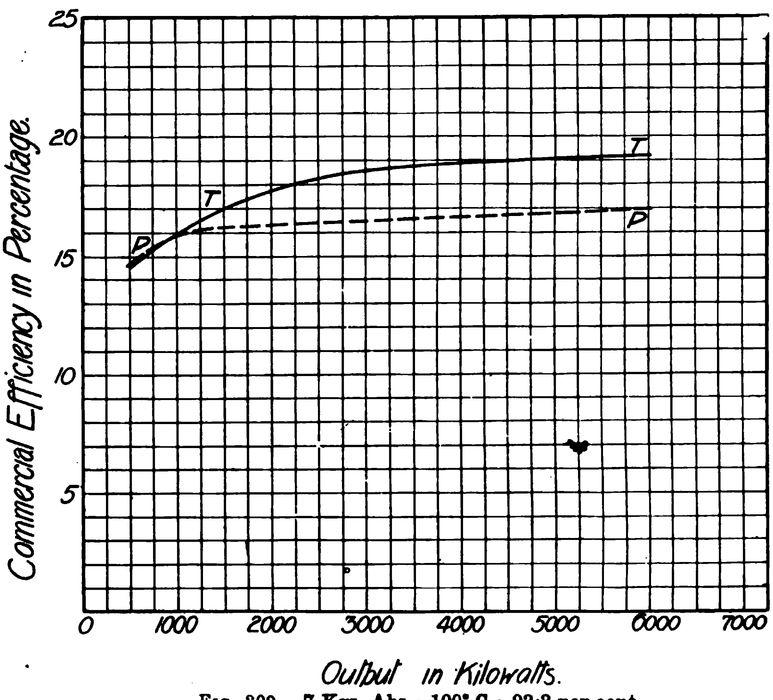


Fig. 309.—7 Kgs. Abs.; 100° C.; 93·3 per cent.
100 Lbs. Abs.; 180° F.; 28 Ins. (From Fig. 299.)

Figs. 307 to 310.—Comparisons of Commercial Efficiencies at
At two Admission Pressures and two

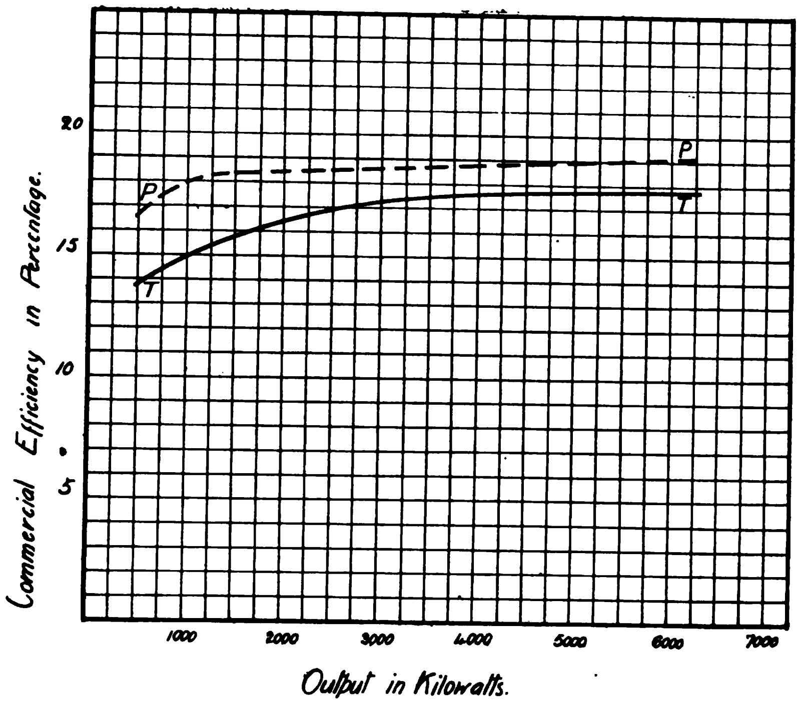


FIG. 308.—16 Kgs. Abs.; 100° C.; 86·6 per cent.
225 Lbs. Abs.; 180° F.; 26 Ins. (From Fig. 296.)

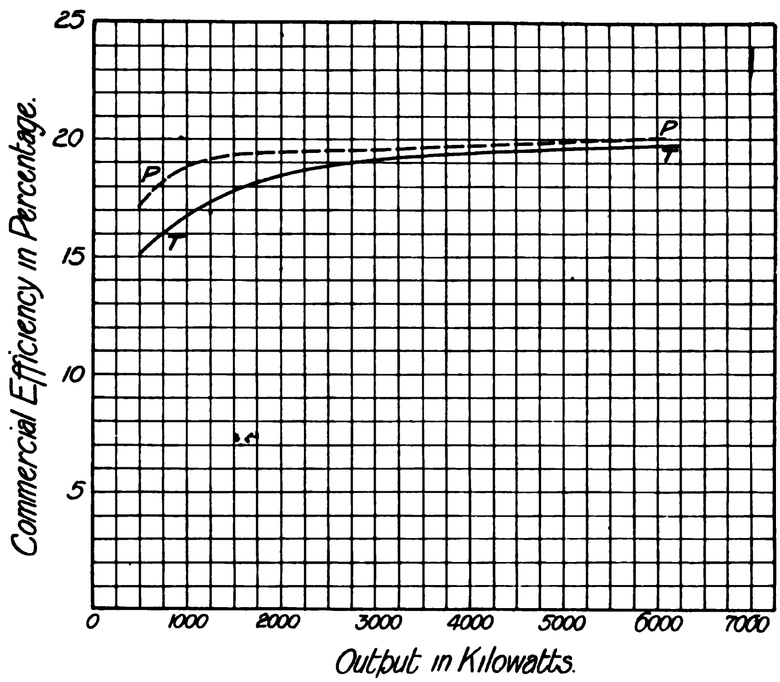
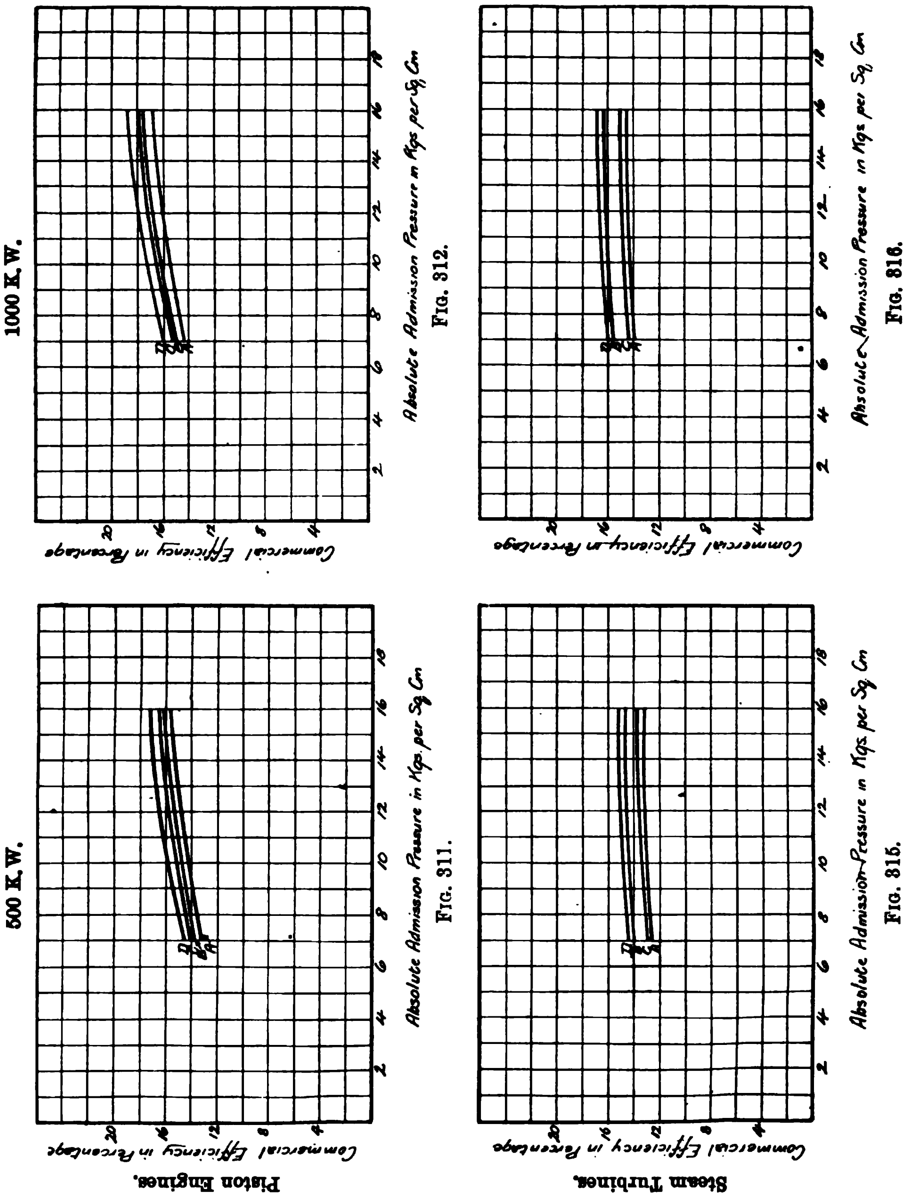


FIG. 310.—16 Kgs. Abs.; 100° C.; 93·3 per cent.
225 Lbs. Abs.; 180° F.; 28 Ins. (From Fig. 298.)

Full Load of Piston Engines—(P)—and Steam Turbines—(T)—(Parsons).
Exhaust Pressures. Superheat 100° C. in all.



FIGS. 311 to 318.—Comparisons of Commercial Efficiencies of 500 K.W. to 4000 K.W. Steam

A	means	50° C.	Superheat	and	86·6
B	,,	,,	,,	,,	93·3
C	,,	100° C.	,,	,,	86·6
D	,,	,,	,,	,,	93·3

4000 K.W.

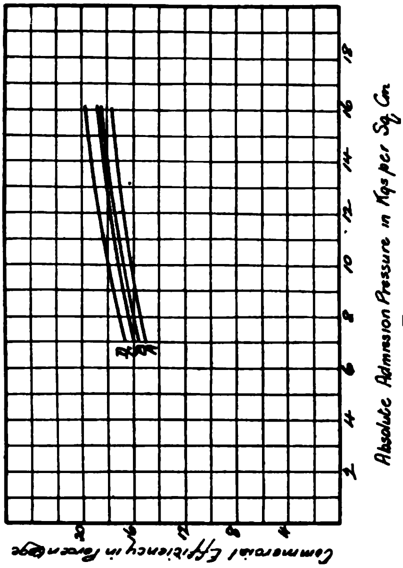


FIG. 314.

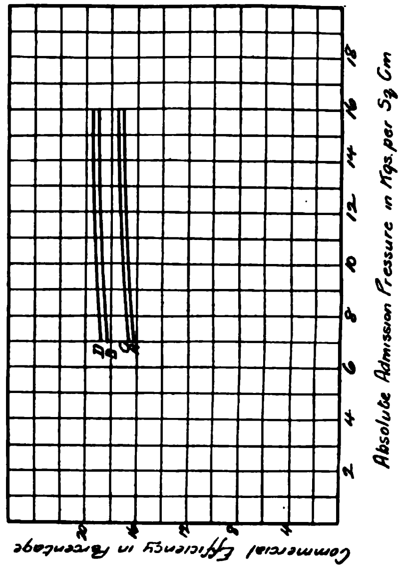


FIG. 318.

2000 K.W.

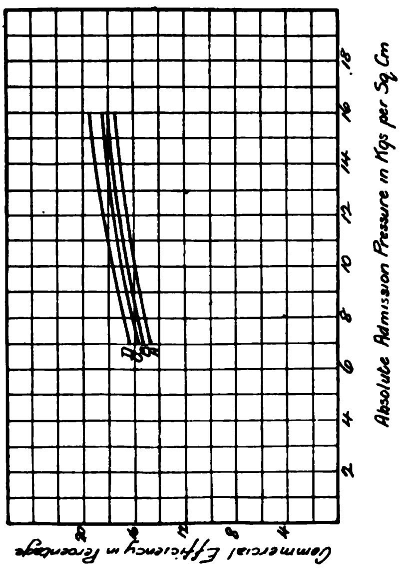


FIG. 313.

Piston Engines.

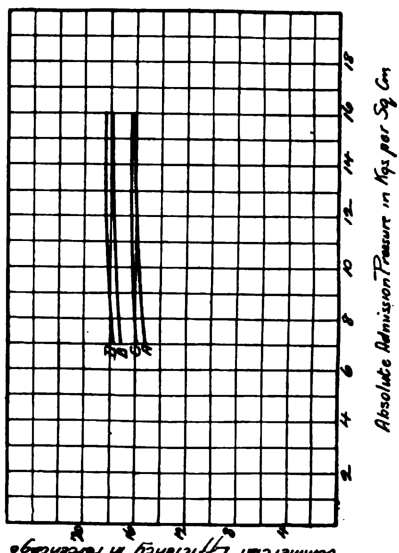


FIG. 317.

Steam Turbines.

Turbines and Piston Engines at Pressures from 7 to 16 Kgs. Abs. (100 to 225 Lbs.).

per cent. Vacuum (90° F. and 26 Ins.).
,, , (,, ,, 28 ,,).
,, ,, (180° F. ,, 26 ,,).
, ,, (,, ,, 28 ,,).

Reference No	Kilowatts Rated Output	Revs per Minute	Abs Pressure in Kgs per Sq. Cm	Exhaust Pressure in Kgs per Sq Cm	Superheat in deg. Cent	Manufactured by	Type of Piston Engine	Tested by	Source of Data
I	170	126	10·2	0·08	0	Van den Kerchove	Poppet Valve Compound Engine	Prof Schröter of Munich	"Electrical Review" New York April 8th 1905 p 575.
II	600	120	11·6	0·045	0	Rice & Sargent	Compound Corliss Engine	Prof Jacobus of Hoboken	. . . . .
III	1000	100	12·4	0·15	45·5	McIntosh & Seymour	Cross Compound Engine		"Electrical World & Engineer." April 2 1904 p 651

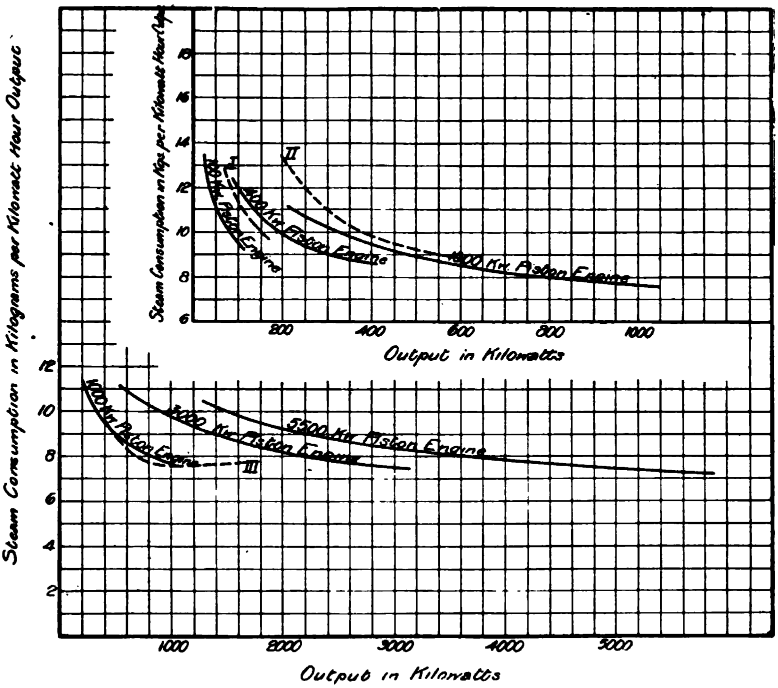


FIG. 319.—Piston Engines.

FIGS. 319 and 320.—Representative Steam Consumptions
All full lines are on our Standard Conditions: 13 Kgs. Abs.;
Dotted Curves: see Table above.

in kilograms per square centimetre, the ordinates indicating the commercial efficiency in percentage.

These curves have been plotted from the efficiency curves of Figs. 303 to 310, and also from the steam-consumption curves of Figs. 258 to 269 and Figs. 280 to 291.

Examining this series of curves, it is evident, by the comparison of the mean slope of the curves for piston engines and that of the

curves for steam turbines, that admission pressure has a much greater effect on piston engines than on steam turbines. While in both cases the efficiency improves as the admission pressure increases, this improvement is, in the case of the steam turbine, very slight indeed.

It will also be noticed that in the case of piston engines the two highest efficiencies are obtained with 100° C. (in our curves) superheat, while the effect of vacuum is not so marked as with steam turbines. Consider Fig. 316, for example:—

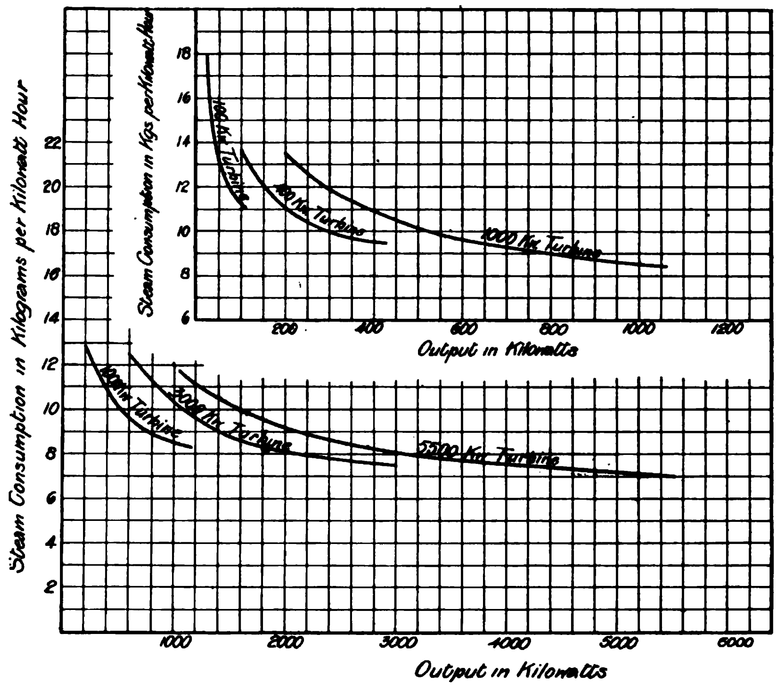


FIG. 320.—Steam Turbines.

of Piston Engines and Steam Turbines at all Loads.
50° C.; 86·6 per cent.; 185 Lbs. Abs.; 90° F.; 26 Ins.

Here we see that keeping the vacuum at 86·6 per cent. and increasing the amount of superheat from 50° C. to 100° C. causes but slight improvement in the commercial efficiency. Now, considering curves C and B, we see that increasing the vacuum from 86·6 per cent. to 93·3 per cent., at the same time *decreasing* the amount of superheat by 50° C., results in a very considerable increase in the commercial efficiency.

These curves, therefore, again bring out the salient characteristics peculiar to the two types of steam turbines as regards the effects of admission pressure, vacuum, and superheat on their respective commercial efficiencies.

Figs. 319 and 320, though not the result of comparisons previously made, should prove to be of some interest. In Fig. 319 is plotted a set of curves (full lines) representing the steam consumption under our standard conditions of 13 kilograms absolute admission pressure, 86·6 per cent. vacuum, and superheat of 50° C., at various loads of piston engines of particular capacities, derived from curves in Fig. 253. The capacities indicated are 100 kilowatt, 400 kilowatt, 1000 kilowatt, 3000 kilowatt, and 5500 kilowatt.

In addition to these, three curves for individual piston engines are shown in dotted lines. A small table is attached, from which the particulars concerning these three engines can be obtained. It will be seen that the trend of these curves is the same as that of the full-line curves which have been derived from our original steam-consumption curves of Fig. 253.

Curve III. here represents the engine which is indicated in Fig. 300 by curve IX., concerning which a few remarks have already been made. This type of engine, met with most commonly in the United States, is so designed and constructed that the maximum steam economy occurs at loads not above $\frac{3}{4}$ of full load.

Fig. 320 is similar to Fig. 319, and comprises steam-consumption curves at various loads of turbines of capacities of 100 kilowatt, 400 kilowatt, 1000 kilowatt, 3000 kilowatt, and 5500 kilowatt. The curves in this figure have been derived from those of Fig. 273, which represent means for steam turbines generally.

In Fig. 321 these sets of curves have been brought together into one diagram, in order to make comparison more easy as regards the relative steam economies of piston engines and turbines generally, at various outputs. In this diagram the dotted-line curves represent piston engines and the full-line curves represent turbines. It is important to note, however, that throughout the previous comparisons steam turbines have been represented by the Parsons type, whereas in the comparison shown in Fig. 321 the curves were obtained from those of Fig. 273, which represent means for steam turbines as a class.

On examining Fig. 321 it is evident that for small capacities up to about 1000 kilowatt output the piston engine is considerably more economical with steam than the turbine, while at the higher capacities the steam turbine shows a slight superiority.

These characteristics have been brought forward and illustrated on several previous occasions in this treatise.

Direct comparisons of the effect of good vacuum on the

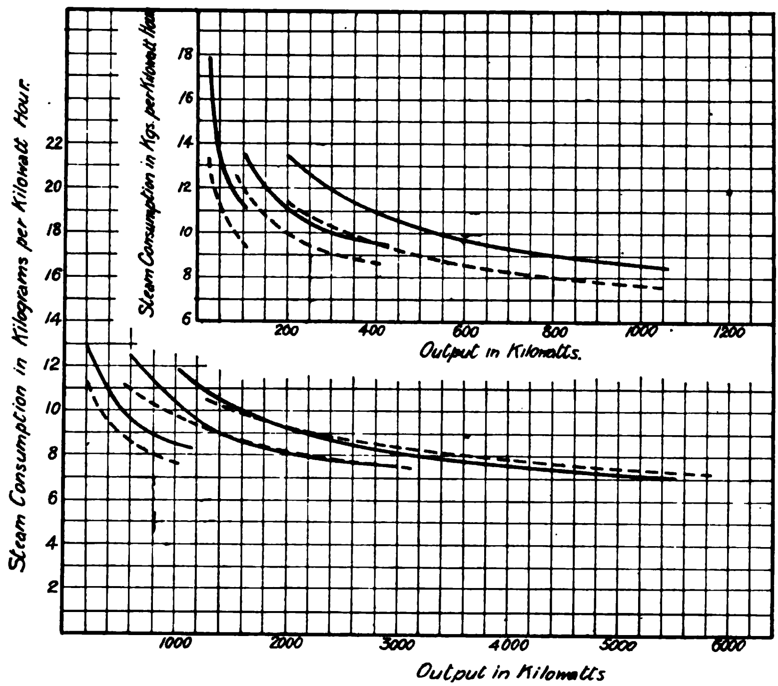


FIG. 321.—Comparison of Representative Steam Consumptions under our Standard Conditions. (From Figs. 319 and 320.)

Dotted Lines are Piston Engines. Full Lines are Steam Turbines.

commercial efficiencies of steam turbines at two pressures, 7 and 16 metric atmospheres absolute (100 and 225 lbs. per sq. in.), and with 50° and 100° Centigrade superheat (90° F. and 180° F.) are more readily made in Figs. 322 to 325, where the full line curves of Figs. 303 to 310 are brought together in pairs.

Comparisons of steam consumptions with 50° Centigrade superheat (90° F.) at two pressures and two vacua can be made from Figs. 326 to 329; and with 100° C. superheat (180° F.) from Figs. 330 to 333.

7 *Kgs. per Sq. Cm.*

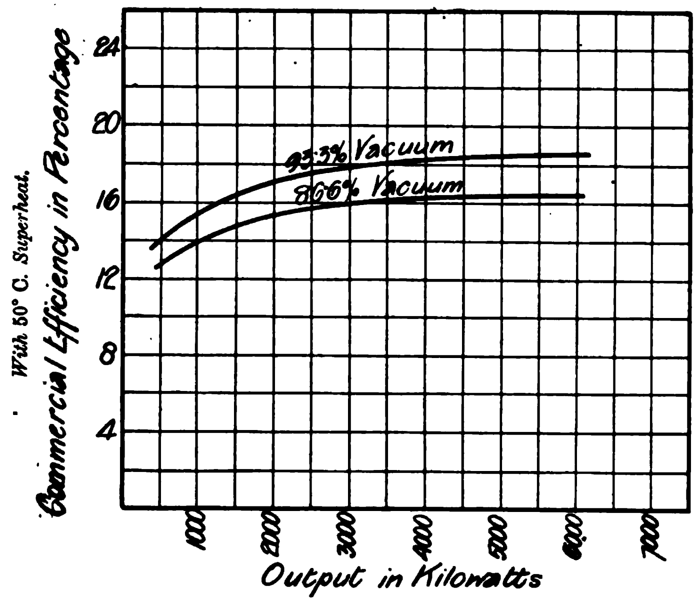


FIG. 322.

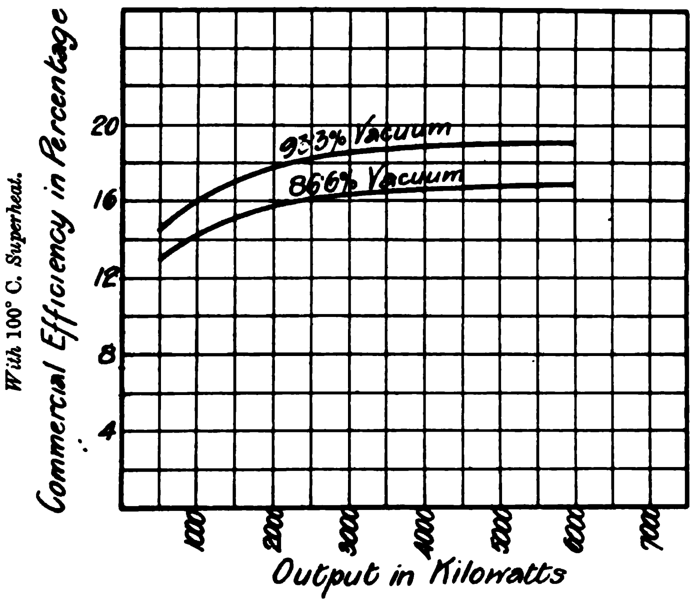


FIG. 324.

FIGS. 322 to 325.—Comparisons of Commercial Efficiencies of **Steam Turbines** 16 Kgs. per Sq. Cm., Vacua of 86·6 per cent. and 93·3

16 *Kgs. per Sq. Cm.*

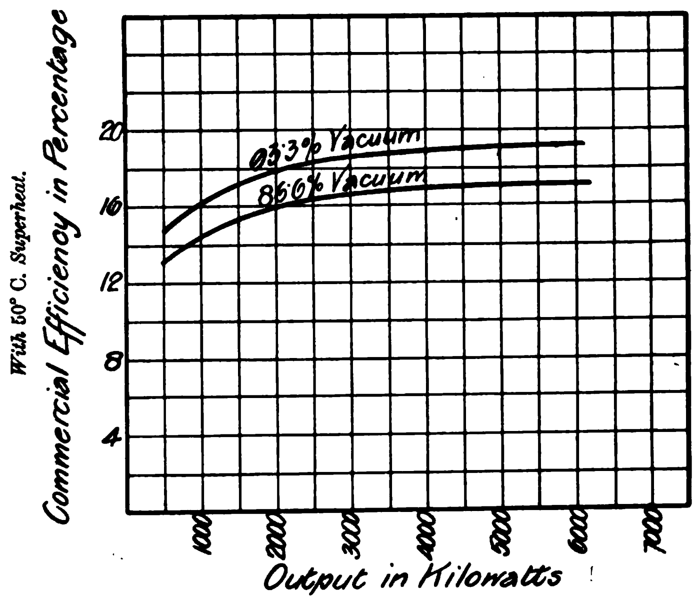


FIG. 323.

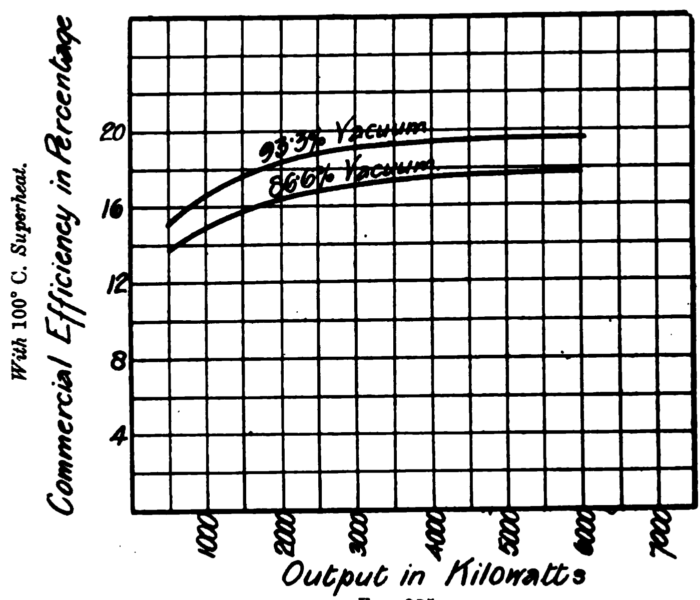


FIG. 325.

under the Extreme Conditions: Absolute Admission Pressures of 7 Kgs. and per cent., with Superheats of 50° and 100° Centigrade.

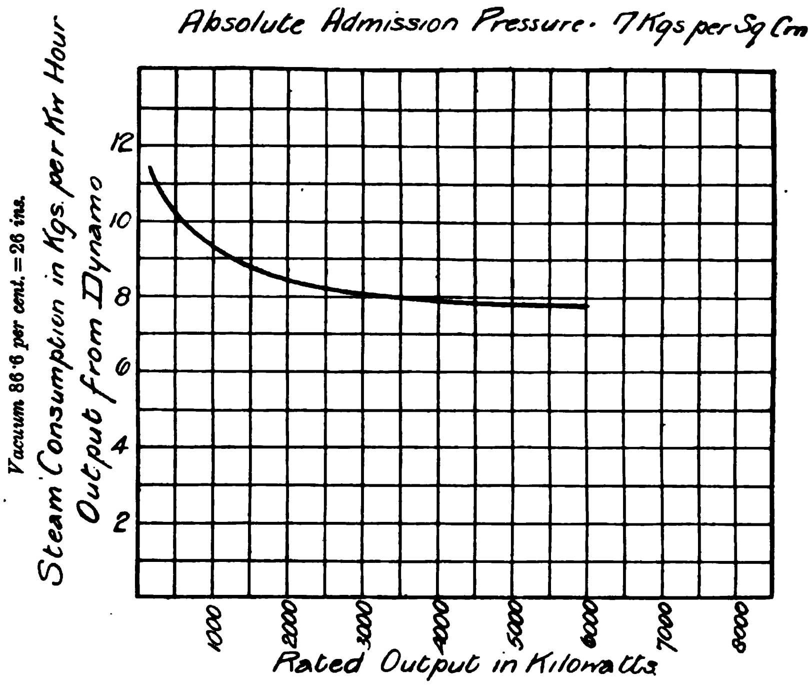


FIG. 326.

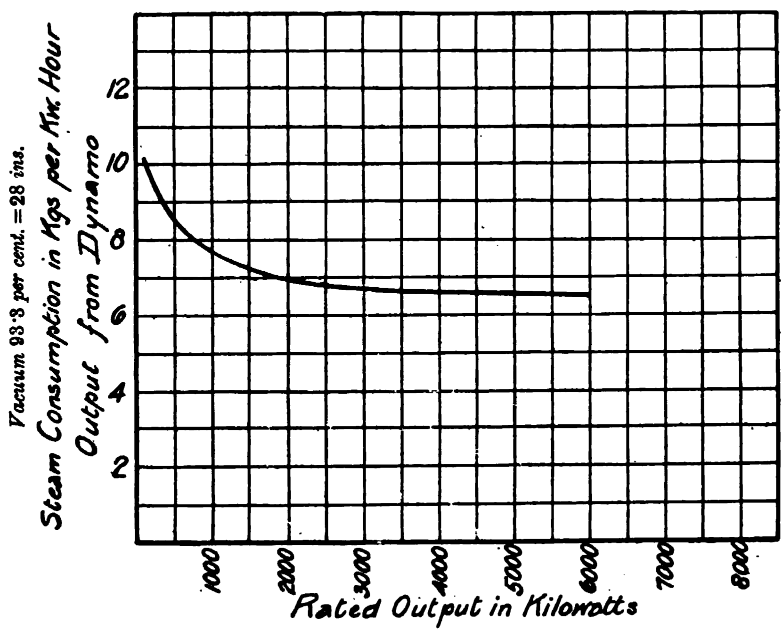


FIG. 328.

FIGS. 326 to 329.—Comparisons of Full-Load Steam Consumptions of Steam Turbines per Sq. Cm., Vacua of 86·6 per cent. and 93·3

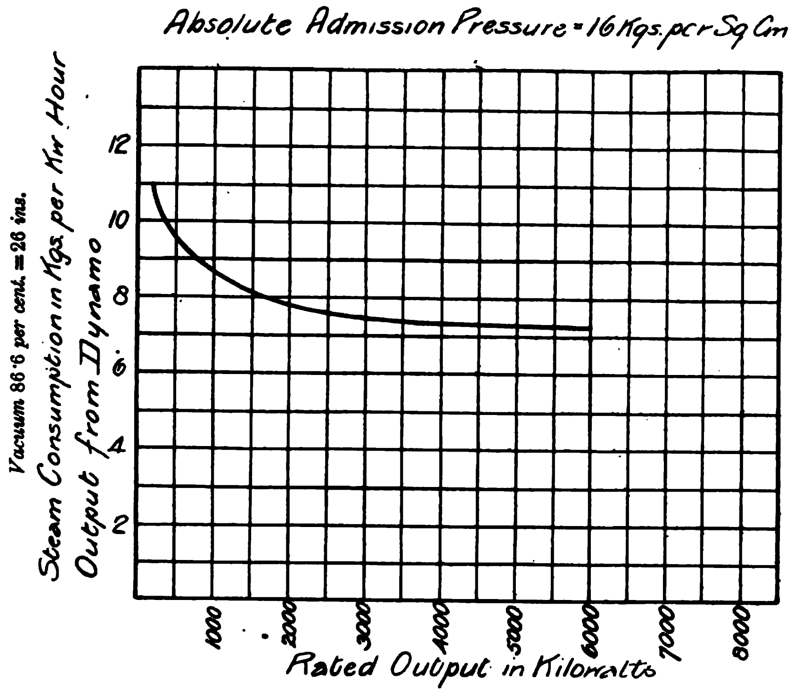


FIG. 327.

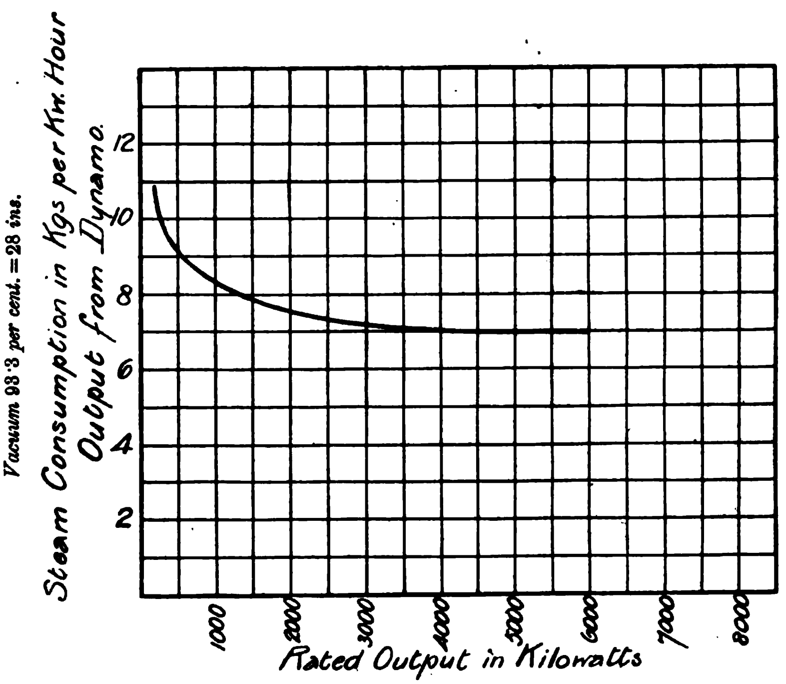


FIG. 329.

under the Extreme Conditions: Absolute Admission Pressures of 16 Kgs. and 7 Kgs. per cent., with a Superheat of 50° Centigrade.

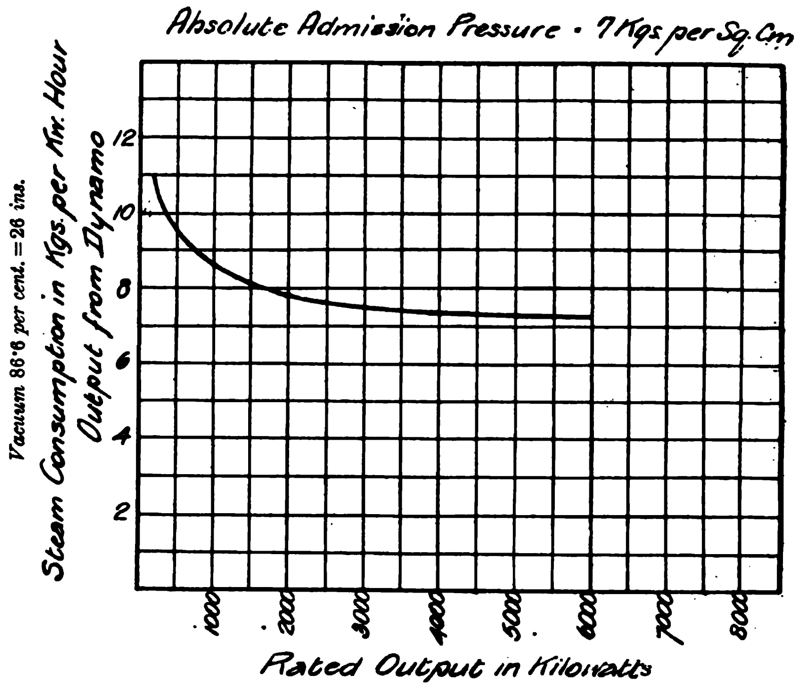


FIG. 330.

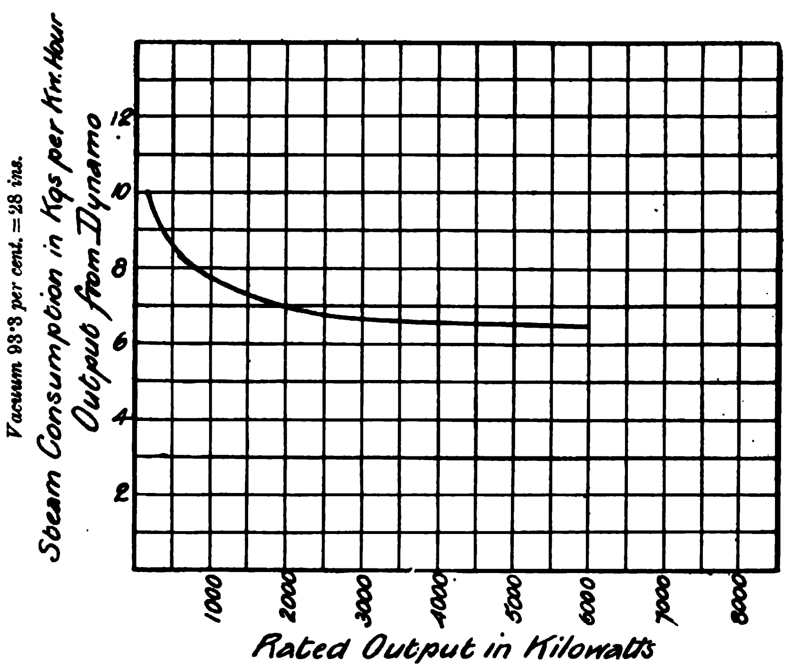


FIG. 332.

FIGS. 330 to 333.—Comparisons of Full-Load Steam Consumptions of Steam Turbines per Sq. Cm., Vacua of 86·6 per cent. and 93·3

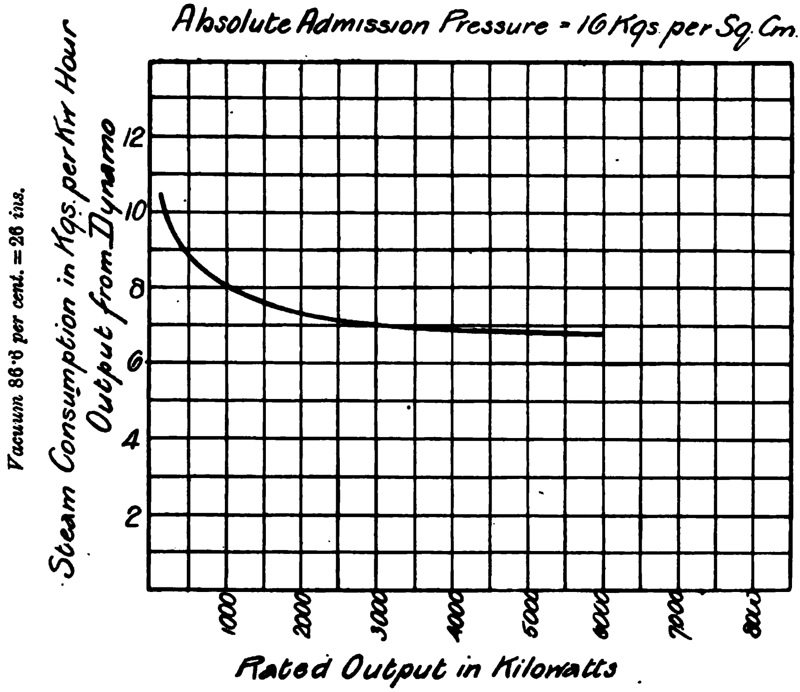


FIG. 331.

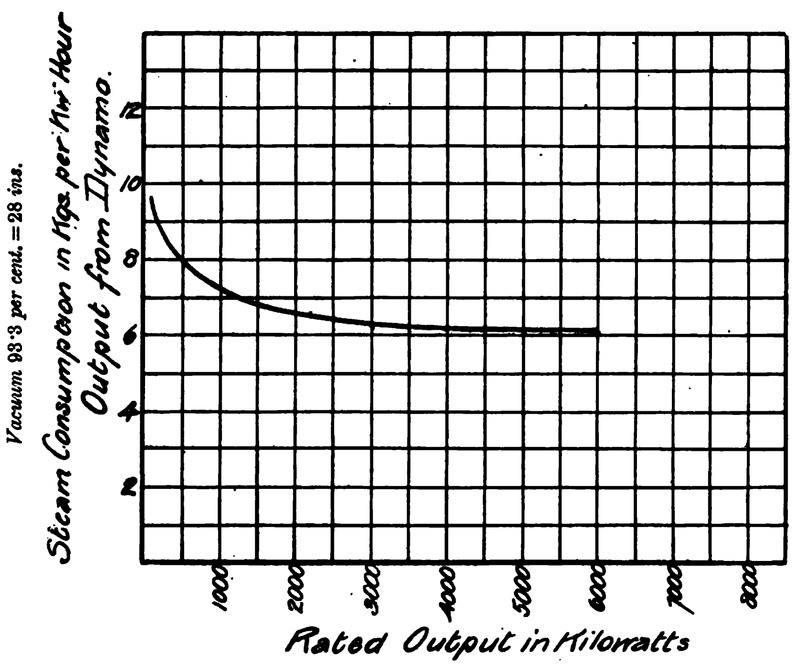


FIG. 333.

under the Extreme Conditions : Absolute Admission Pressures of 16 Kgs. and 7 Kgs. per cent., with a Superheat of 100° Centigrade.

CHAPTER XVII

Steam Pressure, Superheat, and Vacuum in Plants in Operation

To select the most economical plant which fully provides for operation without inconvenience to consumers, and without unnecessary demands upon the operating and maintenance staffs, requires a thorough acquaintance with all that has been done in this direction.

In parallel columns, for facility of comparisons, various details of steam turbine and reciprocating plants, reduced to as simple units as possible, have been arranged, dealing with all sizes of units in existence and all capacities of plants. And these will form a nucleus and a systematic outline for further additions to this data.

The practical value of such an arrangement of data has been demonstrated by years of use of similar accumulations of figures, based on the experience of the authors in the design and operation of power plants, and on their studies of the designs of other engineers.

The writers endeavoured to accumulate data on steam-pressure, superheat, and vacuum in power stations, using all types of steam-driven generators, as well as data on the power consumed by auxiliaries in each type of plant, by asking every Chief Engineer to give answers to a printed list of questions.

The Post Office held back most of the inquiries to foreign engineers, because they ruled it illegal to enclose in an unsealed envelope a stamped envelope to prepay the reply postage on the printed forms. The envelopes for England were then sealed. As so few replies were received, and as considerable variations in the interpretations put upon the questions would have necessitated

revising and supplementing them, it was decided not to go further at present with those questions.

Acknowledgments are expressed in the Preface to those Chief Engineers and Managers who kindly furnished the particulars summarised of plants.

TABLE CII.—PRESSURE SUPERHEAT AND VACUUM.

Summary of 35 named Turbine Plants in Tables (CIII.).
,, 51 ,, Reciprocating Plants in Table (CIV.).

Engines Condensers.	Steam Pressure.					Superheat.						Vacuum.						
	200	185 to 160.	155 to 135.	Under 135.	Not stated.	275.	200 to 150.	140 to 100.	Under 100.	Zero.	Not stated.	28 and over.	27 to 27·9.	26 to 26·9.	24 to 25·9.	Under 24.	Zero.	Not stated.
Turbines with:—																		
Surface Condensers	5	16	5	..	8	2	12	8	1	2	3	12	5	..	..	1	none	11
Barometric . .	..	1	..	..	..	..	2	..	..	..	..	..	1	1	..	..	..	1
Jet	..	..	1	..	..	..	..	..	..	1	..	1	..	..	..	..	..	..
Totals of above Turbine Plants . .	5	17	6	0	7	2	14	8	1	3	7	13	6	1	0	1	0	14
Reciprocating with:—																		
Surface . .	5	19	8	2	..	..	..	11	8	10	4	2	3	8	9	3	..	9
Barometric . .	2	..	..	..	..	..	..	..	..	..	2	..	..	1	..	..	..	1
Jet	..	5	1	..	..	..	1	1	1	4	..	..	2	4	..	..	..	..
Ejector . . .	..	3	..	2	..	..	..	2	..	2	1	..	..	1	2	2	..	..
Reciprocating Non-condensing . .	1	1	2	..	..	..	..	1	..	..	3	..	..	..	..	..	4	..
Totals of Reciprocating Plants . .	8	28	11	4	0	0	1	15	9	16	10	2	5	14	11	5	4	10

Taking here the stations referred to in order of total rated output of plant installed, we give pressure, superheat, and vacuum in each of the following turbine stations.

TABLE CIII.—PRESSURE, SUPERHEAT, AND VACUUM IN USE WITH TURBINES.

	Total K.W. of Turbines.	Boiler Gauge Pressure, lbs. per sq. in.	Superheat °F.	Vacuum (Mercury).	Barometer.	Turbine.	Generator.	Condenser.	Type.	Exciters installed. Volts.	Exciters installed. K.W. Percentage of Main Generators.
1. Chelsea, London, Lots Rd.	44,000	175	150	26in. to 27in.	30	Westinghouse-Parsons	Westinghouse	Simpson	Surface	125	1·1
2. *Interboro' R.T. Co. (Subway) New York*	3,750 turb. *45,000 recip.*	200 ..	275 ..	.. ..	.. ..	,, ..	,, ..	.. ..	,, ..	.. ..	.. ..
3. *Manchester Corporation*	5,100 turb. *29,200 recip.*	200 ..	100 ..	28in. ..	30 ..	Parsons ..	Parsons Siemens	Korting Parsons	Surface ,,	.. ..	.. ..
4. Neasden, M.R. Co., London	14,100	180	180	27in.	..	Westinghouse-Parsons	Westinghouse	..	Barometric	125	1·4
5. Detroit Edison Co., Delray	12,000	200	200	..	..	Curtis	..	..	Surface	..	1·2 and battery
6. Carville, Newcastle	12,000	200	150	28in.	..	Parsons	Parsons	..	,,	..	..
7. St Marylebone, London	..	200	180	..	..	,,	..	..	..	..	..
8. Quincey Point, U.S.A.	10,000	170	65	28in. to 29½in.	..	Curtis	G.E. Co.	Wheeler	Surface	125	1·7
9. Boston Edison Co., U.S.A.	10,000	175	150	28in.	..	,,	..	..	,,	..	..
10. Lancashire Power Co.	6,000	160	150	28in.	..	,,	B.T.H.	..	,,	..	7·5[1]
11. Yorkshire Power Co.	4,500	160	150	28in.	..	,,	,,	Mirrlees	,,	220	10[1]
12. *Neptune Bank, Newcastle*	1,500 turb. *2,100 recip.*	.. ..	.. ..	.. ..	.. ..	Parsons ,,	.. ..	.. ..	,, ,,	.. ..	.. ..
13. *Halifax*	400 turb. *4,200 recip.*	150 ..	100 ..	20in. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
14. *Sheffield, Sheaf St.*	800 turb. *3,600 recip.*	160 ..	zero ..	... ..	.. ..	Parsons ..	Parsons ..	.. ..	Surface ..	.. ..	.. ..
15. ,, Neepsend	3,000	160	100	29in.	..	Parsons	Parsons	Parsons	Surface	..	..
16. Los Angeles, Cal., U.S.A.	4,000	160	110	28in.	..	Curtis four-stage	G.E. Co., New York	Wheeler	,,	..	..
17A. Brimsdown	3,000	160	150	27in.	..	Parsons	Brown-Boveri	Mirrlees	,,	110	10
17B. *St Pancras*	2,000 turb.	185	200	28in	..	,,	Parsons	Parsons	,,	..	..

Items 1, 4, 6, 9, 10, 11, 17A, 18, 27, 32; further details in Chapter XXII.

Waterside No. 2, New York Edison, 31,000 K.W., 175 lbs., 100° F., 28 in. 2 Westinghouse and 2 Curtis Sets. See p. 455.

[1] Exciting and Lighting.

TABLE CIII.—*continued.*

	Total K.W. of Turbines.	Boiler Gauge Pressure, lbs. per sq. in.	Superheat °F.	Vacuum (Mercury).	Barometer.	Turbine.	Generator.	Condenser.	Type.	Exciters installed.	
										Volts.	K.W. Percentage of Main Generators.
17a. *Poplar*	2,000 turb.	160	150	..	..	..	Bruce Peebles	Allen	Surface	65	..
18. English M'Kenna Process Co., Birkenhead	2,250	165	120	27·5in.	30	Willans-Parsons	Siemens	Willans	„	..	..
19. Scarborough	1,945	140	zero	27·3in.	..	„	Parsons	Parsons	„	..	..
20. *Harrogate*	1,050 turb. *850 recip.*	135 ..	140 ..	29·25in. ..	30 ..	Parsons Curtis	„ B.T.H.	„ Allen	„ ..	.. ..	.. ..
21. Newport, U.S.A.	1,500	150	175	28·5in.	..	„	..	..	Surface	..	..
22. *Middlesboro*	600 turb. *1,000 recip.*	140 ..	zero ..	28in. ..	.. ..	Brush-Parsons ..	Brush ..	Cole March't ..	Jet	..	..
23. Shipley	1,170	160	0 to 300	..	..	Parsons	Parsons	Cole March't	Surface	..	..
24. *Kidderminster*	600 turb. *300 recip.*	150 ..	100 ..	28in. ..	.. ..	„ ..	„ ..	Parsons ..	„ ..	.. ..	.. ..
25. *Cork*	500 turb. *500 recip.*	.. 150	.. 100	.. 27in.	.. 30	.. Curtis	.. ..	.. ..	.. Surface	.. ..	.. ..
26. Port Dundas, Glasgow	..	..	..	..	..	Willans	Dick Kerr	..	Surface	..	..
27. Yoker, Clyde Valley E.P. Co.	..	175	150	..	..	Westinghouse	..	..	Surface	..	..
28. Elberfeld	..	..	..	..	..	..	..	..	..	..	..
29. Bristol	..	..	..	..	..	Willans	Dick Kerr	Mirrlees	..	..	..
30. Broad St., Johnston, U.S.A.	..	..	..	..	..	Westinghouse	..	..	..	..	..
31. St Louis Exhibition	2000 K.W. turbine	..	..	..	..	Curtis	G.E. Co., New York	..	..	..	..
32. Motherwell, Clyde Valley E.P. Co.	..	175	150	27·5	..	Westinghouse	..	Mirrlees	Barometric	..	..
33. Shieldhall, Glasgow	..	..	..	..	..	..	..	..	..	..	..
34. Rugby	..	..	..	..	..	Curtis	..	Mirrlees	Surface	..	..

TABLE CIV.—STEAM PRESSURE, SUPERHEAT, AND VACUUM USED WITH RECIPROCATING ENGINES.

	Total Rated K.W.	Pressure lbs. per sq. in.	Superheat °F.	Vacuum Inches Mercury.	Barom. Inches Mercury.	Engines.	Condensers.	Type.
35. Interboro' R.T. (Subway), New York	45,000 recip. *3,750 turb.*	200	..	26	30	Allis[3]	Alberger	Barometric
36. Manhattan Elevated, New York	40,000	2·0	..	..	..	Allis	..	Jet at first, Barometric later
37. Manchester	29,200 recip. *5,100 turb.*	135.160.200	100	28 and 25	29·6	Wallsend Musgrave Yates & Thom Ferranti Goodfellow[4]	Mather & Platt Musgrave Willans & R. Ledwards ,,	Surface ,, Barometric Ejector ,,
38. Vienna	15,000	200	..	..	..	Sulzer	..	..
39. Leeds	12,400	130 180	30° 100°	26in. 26in.	30in. ,,	Bellis M'Laren Hick Hargreaves Fowler	Mirrlees Cole Marchant Storey Hick Hargreaves Fowler	Surface
40. Pinkston	11,200	160	75°	25	29·4	Allis Musgrave Stewart	Mirrlees	Surface
41. Metr. Street Ry., Kansas City	9,000[1]	175	50°/100°	26	29·5	Allis	Wheeler	..
42. Salford	6,400	160	100°	26	..	Browett	Bailey	Jets
43. West Ham	5,700	150	110°	25	30	Ferranti	Allen	Surface
44A. C.L.Ry., London	5,100	160	zero	26·5	30	Allis	Allis	Jet 1900 Surface 1905
44B. Mersey Ry.	3,750	170	..	25	..	Westinghouse	Weir Marine	Surface
45. Kelham I., Sheffield	3,675	160	100°	26	..	Cole Marchent & Morley	Wheeler	Surface
46. Alpha Place, Chelsea	3,500	175	zero	zero	..	Willans	Non-cond.	..
47. Lowell, U.S.A.	3,500	140	zero	27·5	30	Cooper	Cooper	Jet
48. G.N. and C. Ry., London	3,450	160	zero	..	..	Musgrave	Wheeler	Surface
49. Dundee	3,000	160	120°	15	30	Willans	Allen	Surface
50. Paisley	3,000	180	100	26	30·4	Adamson Paxman Ferranti	Körting	Ejector
51. Wimbledon	1,685[2]	150	100	27	..	Browett Willans	Alley	Surface
52. Reading	2,675	160	140	27	..	Fowler Belliss Willans	Fowler Wheeler	Surface and Jet

[1] *Adding one 5000 Turbine, 1905.* [2] *1000 extension on order Curtis Turbine.* [3] *See also Turbines, p. 424, No. 2.* [4] *See also Turbines, p. 424, No. 3.*

53. Ilford	2,600	160	90/100	26	29·8	Bellis Willans	Allen	Surface
54. Ringsend, Dublin	2,500	160	..	..	..	Allis	Wheeler	Surface
55. Leicester	1,700[1]	165	zero	25	30	Yates & Thom	Mirrlees	,,
56. Wolverhampton	2,380	180	100	25	..	Willans Peache Belliss	Ledward, Körting, Evans	Ejector ,, Surface
57. Greenock	2,000	200	85	25	..	,,	Mirrlees	,,
58. East Ham	1,925	150	60°	22·5	..	Musgrave	Wheeler	,,
59. Lowestoft	1,750	160	50/100	21 to 24	..	Browett Willans Musgrave	Betrams Wheeler	,, ,,
60. Burton-on-Trent	1,660	160	zero	28	..	Willans Alley & M'Lellan Fowler	Cole Marchent Edwards Fowler Yates & Thom	,, Jet ,, ,,
61. Hull	1,560	155	..	..	..	Belliss	Belliss	Surface
62. Stalybridge	1,500	180	zero	26	..	Yates & Thom	Y. & T.	Jet
63. Burnley	1,500	130	zero	24·5 to 26·5	..	Belliss & M. Burnley I. W. Co.	Körting Burnley	Ejector Jet
64. Walsall	1,300	140	..	..	..	Bumstead & Co.	Beliss	Surface
65. Bury	1,260	160	160	26	..	Belliss.	Worthington Walmsley	Jet ,,
66. Eastbourne	1,200	150	120	zero	..	Ferranti, Willans, Peache	non-cond.	..
67. Gloucester	1,150	160	some	27	..	Belliss Willans	Blake Knowles	Jet
68. Kirkcaldy	1,030	200	zero	zero	..	Browett	Summers & Scott non-cond.	,, ..
69. Barrow	1,025	160	100/150	24/28	..	Willans	Wheeler Alley & M'L.	Surface ,,
70. Nelson	1,000	150	zero	26/27	..	Willans	Cole Marchent	,,
71. Smithfield Mkt. E. S. Co., London	965	140	zero	zero	..	Belliss Davey Paxman	non-cond.	..
72. Gillingham	950	200	100	27	29·5	Willans	Alley & M'Lellan	Surface
73. Carlisle	87[illegible]	160	zero	20/27	..	Willans	Ledwards	Ejector
74. Chatham and District	675	160	zero	25/26	..	Yates & Thom	Wheeler	Surface
75. Barnes	570	160	90	25	..	Belliss	,,	,,
76. Worthing	538	165	..	21	..	Allen	Ledward	Ejector
77. Guernsey	510	160	100/130	24	30	Belliss Campbell	Cole Marchent	Surface
78. Cleethorpes	300	125	zero	26	..	Robb Armstrong	Wheeler	Surface
79. Partick	..	..	..	...	..	..	Mirrlees W. Co.	..
80. Manx	..	..	..	..	..	..	Mirrlees W. Co.	..
81. Govan	..	..	..	...	..	..	M rrlees W. Co.	..
82. Burton	..	..	..	..	...	..	Cole Marchent	...

[1] 1000 extension being installed.

Mr J. R. Bibbins put before the American Street Railway Association [1] a summary of an investigation of the general practice as to pressure, superheat, and vacuum in forty-six unnamed plants, using or installing a single type of steam turbine, the Westinghouse Parsons. It is not possible to say how many of the Westinghouse plants included in Tables CIII., CIV., were in Mr Bibbins' summary, of which we repeat certain details in Table CV.

TABLE CV.—PRESSURE, SUPERHEAT, AND VACUUM.

A Summary of forty-six unnamed Westinghouse Steam Turbine Plants, investigated by Mr J. R. Bibbins, *American Street Railway Association*, Oct. 1904, Table B, p. 201.

The figures represent the number of plants working under conditions stated at the head of each column, of capacity and for the purpose stated on the left hand.

Limits of Capacity in Rated K.W. of Plant.	Use made of the Supply.	Limits of Steam Pressure.				Limits of Superheat. Degrees Fahrenheit added.					Limits of Vacuum. Inches of Mercury.			
		200.	200 to 175.	175 to 150.	150 to 125.	200.	200 to 150.	150 to 100.	Below 100.	Zero.	28.	28 to 27.	27 to 26.	26.
40,000	Traction	1	..	..	..	..	..	..	..	..	..	..	..	..
25,000 to 10,000	"	3	..	..	..	..	..	..	..	..	..	..	..	..
10,000 to 5,000	"	2	..	..	..	..	..	..	2	..	..	..	..	2
5,000 to 3,000	Power	..	1	..	..	..	1	..	..	..	..	..	1	..
4,000 to 2,000	Traction	..	..	..	2	..	..	..	..	2	..	..	..	2
	Power	1	..	..	..	..	..	1	..	..	..	..	..	1
	Light and Power	..	..	..	3	..	..	..	3	..	..	..	3	..
2,000 to 1,000	Traction	..	2	..	..	..	..	2	..	..	..	2	..	..
	Power	..	..	..	4	..	..	..	4	..	4	..	..	..
	Light and Power	..	4	..	..	..	..	..	..	4	4	..	..	..
Below 1,000	Traction	..	..	5	..	..	5	..	..	..	..	..	5	..
	Power	..	..	14	..	..	..	..	..	14	..	14	..	..
	Light and Power	..	..	4	..	..	..	4	..	..	..	4	..	..
Totals .	..	7	7	23	9	..	6	7	9	20	8	20	9	5

[1] Report of American Street Railway Association, St Louis Meeting, Oct. 1904,—"Steam Turbine Power Plants."

CHAPTER XVIII

CONDENSERS

A LIMITED amount of data on the condensers used with some of the plants mentioned in Tables CIII. and CIV. is tabulated below.

The conditions under which each station is placed with reference to condensing water largely determines the type and size of condensing plant; but, in the absence of complete information, it is of interest to compare the surface of condensers per rated kilowatt of plant; also the relation between condenser surface and boiler heating surface, and the pounds of steam condensed per hour by each square foot of cooling surface in the condensers.

Extra Cost of High Vacuum.—Steam turbine manufacturers are, naturally, continually drawing attention to the advantages derivable from high vacuum and superheat, and the question is as often raised as to the increased cost of plant and of running expense.

The reduction in steam consumption due to increase in vacuum and in superheat has been investigated in the chapters on Parsons and de Laval turbines, and a few instances mentioned of tests in this connection on other types of turbines. It remains for attention to be turned to the economy of installing plant, at increased cost, for producing the higher vacuum.

Mr J. R. Bibbins calculated three cases of a 2000 kilowatt plant in which the condenser equipment to give 28 inches vacuum costs £800[1] more (£0·4 per rated kilowatt) than an equipment which would give only 26 inches vacuum. See p. 434, Table CXI.

[1] The *extra* cost is stated by Mr Bibbins. For total cost of other plants see Table VII., p. 8, items 28 to 30.

TABLE CVI.—STEAM TURBINES

Item Numbers in Table CIII.		Steam Generator. Largest Unit Rated K.W.	Steam Generator. Lbs. Steam per K.W.H. at Rated Full Load.	Surface Condensers in Table CVI. Maker.	Number.	Surface of each. Total sq. feet.	Surface of each. Sq. feet per Rated K.W.	Ratio Condenser Surface to Boiler Surface.	Number of times Water passes full length.	Rated Capacity. Lbs. per Hour.	Rated Capacity. Lbs. per Hour per sq. ft. Condenser Surface.
1	**Chelsea, Lots Rd.**	5,500	..	Simpson	8	15,000	2·7	35%	1 c.c.	..	..
26	Port Dundas, Glasgow	3,000	..	(See Fig. 334)	..	11,000	3·7	..	..	..	..
8	**Quincy Point, U.S.A.**	2,000	..	..	5	8,500	4·2	57%	..	..	..
31	**Curtis Turbine at St Louis Exhibition 1903**	2,000	..	..	..	..	..	..	..	..	..
16	**Los Angeles, U.S.A.**	2,000	20·5	Wheeler	2	6,000	3	30% oil fuel	..	..	6·8
7	**St Marylebone, London**	2,000	..	..	..	..	..	..	..	..	..
3	***Manchester***	1,800	19·8	..	2	..	..	..	..	..	..
15	**Sheffield, Neepsend**	1,500	17·5	..	2	3,000	2	48%	..	..	8·7
27	**Yoker, Clyde Valley, E.S. Co.**	1,500	..	..	2	6,150	4·11[1]	..	3 c.c.	40,000	..
11	**Yorkshire P. Co.**	1,500	..	Mirrlees	3	4,500	3	52%	4	..	5·4
10	**Lancashire P. Co.**	1,500	16·4	..	4	4,500	3	52%	4	37,000	8·2
2	*Interboro' Rapid Transit Subway, New York*	1,250	21	..	3	..	..	..	..	..	..
28	*Elberfeld*	1,000	..	..	..	4,000	4	..	..	..	..
29	*Bristol*	1,000	..	Mirrlees-Watson	..	..	..	..	..	12,000	..
17A	**Brimsdown**	1,000	under 17	Mirrlees-Watson	3	2,500	2·5	33%	..	25,000	10
17B	St Pancras	1,000	16·5	..	..	..	..	..	..	..	..
18	English M'Kenna Co.	750	..	Willans	3	2,500	3·3	..	..	..	..
20	*Harrogate*	750 300	.. 19·5	Allen Parsons	1 1	2,600 ..	3·4 ..	.. ..	.. ..	.. ..	.. ..
30	Broad Street, Johnstown, Pa., U.S.A.	..	..	..	..	..	..	..	..	..	..
19	**Scarborough**	500 300 150	22·6 24 28·1	.. .. ..	2 2 1	2,000 1,200 400	4 4 2·6	.. .. ..	.. .. ..	.. .. ..	.. .. ..
34	Rugby	500	..	M. W. Co.	..	..	..	..	2 c.c. Test at	11,000 8,400	.. ..
23	**Shipley**	1×450 3×240	..	Cole M. & M.	1 1	1,200 1,000	1·9	..	Test at Test at	10,000 10,000	.. ..
24	*Kidderminster*	300	..	Parsons	2	..	..	..	..	..	..

TABLE CVII.—SOME TURBINES AND ENGINES

36	Manhattan (Elevated), New York	5,000	13 per I.H.P. guaranteed	Worthington and 150 H.p. motor	16			Nil.		..	Nil.
35	Interboro' Rapid Transit Subway, New York (see also 2 above)	5,000	16·5	Alberger & 150 H.p. motor	18			„		..	„
32	**Motherwell Clyde Valley E.S. Co.**	..	..	Mirrlees-Watson Co.	..			„		80,000	„
4	**Neasden, London, Metropolitan Ry. Co.**	3,500	17	..	..			„		..	„
37	Manchester Corporation	1,500	..	Willans & Robinson	..			„		..	„
33	Shieldhall, Glasgow	3×400 1×250	..	Mirrlees-Watson Co.	..			„		48·000	„

[1] Yoker 1 inch tubes 14·5 feet long. c.c. means Counter Current.

WITH SURFACE CONDENSERS.

Item Number.	Vacuum. Inches.	Vacuum. Barometer.	Air Pumps. Power consumed at Rated Full Load. Power to Air Pumps.	Circulating Pumps. Head, including Friction, Feet.	Circulating Pumps. Power consumed at Rated Full Load.	Percentage of Rated Output of Main Generator used by Air Pump.	Circulating Pump.	Lift Pump.
1	26 to 27	30	..	..	..	..	..	..
	..	..	..	..	..	..	..	..
8	28 to 29·5	30	25 amp. per phase, 3 phases. 370 volts per phase.	..	60 amps. per phase. 370 volts.	..	..	..
31	..	..	..	..	..	1·4	5	0·5
16	28	29·5	21 K.W.	30	62 K.W.	1·	3·1	..
	..	..	..	..	..	..	..	..
3	28	29·0	..	..	..	..	..	..
15	29	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..
11	28	30	..	..	..	..	..	..
10	28	30	..	..	..	..	..	..
	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..
17A	26 to 27	30	5 K.W.	5	18·5 K.W.	0·5	1·9	..
18	..	..	..	..	..	..	..	..
20	27·5	30	4·2 K.W.	27	27·5 K.W.	0·6	3·7 [1]	..
20	29	29·75	4 K.W.	6	6·5 K.W.	0·5	0·9	..
30	28·5	29·75	..	3	..	..	..	..
	..	..	..	..	..	1·6	0·9	..
19	27·3	29	..	..	..	..	..	..
,,	26·8	29·7	..	..	..	..	..	..
,,	27·1	29·8	..	..	..	..	..	..
34	27·6	29·95	..	..	..	..	..	..
,,	28·3	29·77	..	..	..	..	..	..
23	26·1	29·77	10 E.H.P.	zero	2·7 B.H.P.	..	..	..
,,	25·2	30			See Air Pump.			
24	28	..	..	..	..	..	..	..

WITH BAROMETRIC JET CONDENSERS.

Item Number.	Inches.	Barometer.	Power to Air Pumps.	Head.	Power consumed at Rated Full Load.	Air Pump.	Circulating Pump.	Lift Pump.
36	28	..	..	..	90 H.P. jet original arrangement. 70 H.P. barometric revised arrangement. 6 H.P. dry air pump	..	..	..
35	26	30	..	..	..	..	..	..
	..	..	..	..	..	..	..	..
4	27	30	..	..	..	..	..	..
37	25	29·6	..	..	..	..	..	..
33	26	30	..	..	..	..	..	..

[1] 3·7 K.W. include lift pump.

Items 1, 4, 6, 9, 10, 11, 17A, 18, 27, 32. See also Chapter xxii.

TABLE CVIII.—SOME TURBINES AND

Item Number.		Steam Generator. Largest Unit Rated K.W.	Steam Generator. Lbs. Steam per K.W.H. at Rated Full Load.	Surface Condensers in Table CX. Maker.	Number.	Surface of each. Total sq. feet.	Surface of each. Sq. feet per Rated K.W.	Ratio Condenser Surface to Boiler Surface.	Number of times Water passes full length.	Rated Capacity. Lbs. per Hour.	Rated Capacity. Lbs. per Hour per sq. ft. Condenser Surface.
47	Lowell, Boston and N. St. Ry. Co.	1,600 1,500 400	21·5 22·2 23	.. .. ..	.. .. ..			Nil. ,, ,,		.. .. ..	Nil. ,, ,,
22	Middlesboro'	600	24·5	Cole Marchent & Morley	1			,,		..	,,
62	Stalybridge	500	19	Yates & T.	3			,,		..	,,
67	Gloucester	300	24·8	Blake Knowles, Summers & Scott	..			,,		..	,,

TABLE CIX.—SOME

Item Number.		Largest Unit Rated K.W.	Lbs. Steam per K.W.H. at Rated Full Load.	Maker.	Number.	Total sq. feet.	Sq. feet per Rated K.W.	Ratio Condenser Surface to Boiler Surface.	Number of times Water passes full length.	Lbs. per Hour.	Lbs. per Hour per sq. ft. Condenser Surface.
86	Maker's Statement	(1 000 B. H.P.)	..	Körting	..					..	Nil.
50	Paisley	800K.W.	24	,,	..			,,		..	,,
56	Wolverhampton	500K.W.	28	,, 1 Ledwards 2	..			,,		18,000	,,
63	Burnley	320	33	Körting	..			,,		..	,,
20	Harrogate	300	22·5	..	..			,,		..	,,
22	Middlesboro'	300 300 100	22 26·2 28	.. .. ..	.. .. ..			,, ,, ,,		.. .. ..	,, ,, ,,
76	Worthing	250	24·3	..	..			,,		..	,,

TABLE CX.—RECIPROCATING ENGINES

Item Number.		Largest Unit Rated K.W.	Lbs. Steam per K.W.H. at Rated Full Load.	Maker.	Number.	Total sq. feet.	Sq. feet per Rated K.W.	Ratio Condenser Surface to Boiler Surface.	Number of times Water passes full length.	Lbs. per Hour.	Lbs. per Hour per sq. ft. Condenser Surface.
41	Metr. St. Ry., Kansas City	3,000	19	..	..	10,000	3·3	..	..	..	..
40	Pinkston, Glasgow	2,500 600	13·5	Mirrlees-Watson Co.	4 2	7,000[1] 2,800[2]	2 8	41%	..	..	8·5
37	Manchester	1,800	..	..	..	..	..	..	..	..	..
39	Leeds	1,400	..	Cole Marchent	..	..	2 8	..	..	..	..
,,	Tests furnished by Mirrlees-Watson Co.	..	..	Mirrlees-Watson Co	1 1	3,500 3,500	.. ..	.. ..	.. ..	.. ..	9·1 9·1
53	Ilford	1,000	18 32 non-cond.	Allen	1	2,700	..	18%	..	..	..
49	Dundee	825	22	..	2	2,000	..	30%	..	..	..
48	G.N. and C.R., London	800	..	Wheeler	4	2,400	8		..	..	..
58	East Ham	750	28	..	4	2,100 to 1,200	..	23%	..	..	..
51	Wimbledon	625	24	Alley & M'Lellan	..	3,300	..	17%	..	..	..
79	Partick	..	..	M. W. Co.	1	2,300[3]	..	..	..	..	7·8
,,	Test at 66% of its rated capacity, furnished by Mirrlees-Watson Co.	..	..	..	1	2,300	..	..	..	..	5·2

[1] 2,690 1-inch tubes. [2] 1,072 1-inch tubes. [3] Tubes 0·75 inch, 6·8 feet long.

ENGINES WITH JET CONDENSERS.

Item Number.	Vacuum. Inches.	Vacuum. Barometer.	Air Pumps. Power consumed at Rated Full Load.[1] Power to Air Pumps.	Circulating Pumps. Head, including Friction, Feet.	Circulating Pumps. Gallons per Minute Rated.	Circulating Pumps. Power consumed at Rated Full Load.	Percentage of Rated Output of Main Generator used by Air Pump.	Percentage of Rated Output of Main Generator used by Circulating Pump.	Percentage of Rated Output of Main Generator used by Lift Pump.
47	27·5	30	..	23	..	..	6	..	..
"	"	"	..	..	..	..	6	..	..
"	..	..	..	..	..	..	8·7	..	..
22	28	..	..	..	..	..	..	..	..
62							..		
67	26	..	..	..	..	..	..	..	..
	27	30	..	..	..	..		..	..

EJECTOR CONDENSERS.

Item Number.	Inches.	Barometer.	Power to Air Pumps.	Head, including Friction, Feet.	Gallons per Minute Rated.	Power consumed at Rated Full Load.	Air Pump.	Circulating Pump.	Lift Pump.
86	24	30	..	..	..	17·5 B.H.P. plus pipe friction.	..	..	..
50	26	30·4	..	20	..	..	..	..	..
56	25	..	..	18	..	18 K.W.	..	..	..
63	24·5 to 26·5	30	..	15	..	8 K.W.	2·5	..	..
20	23	29·75	..	10	..	..	..	..	..
22	25	..	..	..	..	..	..	..	..
"	25	..	..	..	..	..	..	..	..
"	25	..	..	..	..	..	..	..	..
76	21	..	..	..	..	17 K.W.	6·8	..	..

WITH SURFACE CONDENSERS.

Item Number.	Inches.	Barometer.	Power to Air Pumps.	Head, including Friction, Feet.	Gallons per Minute Rated.	Power consumed at Rated Full Load.	Air Pump.	Circulating Pump.	Lift Pump.
	..	..	..	..	..	..	..	..	..
40	25 at Condenser[1]	29·4	15 K.W.[2]	12·5	4,000 main	30 K.W.	0·6	1·2	..
	23 at Engine	29·4	7 K.W.		1,600 aux.	15 K.W.	..	..	..
	25	29·4							
37	28	29·6	..	..	..	..	..	..	..
	..	..	..	..	..	..	..	..	..
39	26·6	29·6	299 lbs. steam per hour	17	..	310 lbs. steam per hour	1·0	1·0	..
	26·5	29·6	6·5 K.W.	25·75	..	10·4 K.W.	0·5	0·7	..
53	26	29·8	6 K.W.	27	..	23 K.W.	0·6	2·3	..
49	15	30	6·6 K.W.	35	..	28·6 K.W.	0·8	3·5	..
	..	..	..	..					
58	22·5	30	..	40	..	..	..	..	.
51	27	30	..	22·5	..	..	..	..	..
	26	30	..	..	1,275 gal.	..	..	..	..
	28·27	30·17	17·9 K.W.[3]	26·8	1,450 ,,	..	..	..	.
	..	..	..	..	..	..	..	..	..

[1] *Power*, Jan. 1904. [2] 150 R.p.m. direct-coupled motor. [3] One motor drives both air and circulating pumps.

TABLE CX.—

Item Number.		Steam generator. Largest Unit Rated K.W.	Steam generator. Lbs. Steam per K.W.H. at Rated Full Load.	Surface Condensers. Maker.	Number.	Surface of Each. Total sq. feet.	Surface of Each. Sq. feet per Rated K.W.	Ratio Condenser Surface to Boiler Surface.	Number of times Water passes full length.	Rated Capacity. Lbs. per Hour.	Rated Capacity. Lbs. per Hour per sq. ft. Condenser Surface.
80	Manx E. Ry. . . .	..	..	M. W. Co.	1	1,800	..	..	..	..	10
	Test at 55% of its rated capacity furnished by Mirrlees-Watson Co.	..	..	..	..	..	..	..	..	..	5·5
81	Govan	..	..	M. W. Co.	1	1,800	..	..	..	..	10
				M. W. Co.	2	1,300	..	..	..	..	10
82	Burton	500	..	Cole Marchent	..	..	..	..	..	..	..
83	Ringsend, Dublin . .	500	17	Wheeler	3	2,400	2·9	24%	..	..	..
55	Leicester . . .	500	23	Mirrlees W.	..	2,500	..	..	..	..	..
61	Hull	800	..	Belliss	2	2,000	..	..	..	..	..
20	Harrogate . . .	125	27·5	..	..	..	..	..	..	..	..
17A	Brimsdown . . .	..	..	..	..	..	..	..	..	..	..
74	Chatham and District .	200	..	Wheeler	1	1,200	2	..	..	..	..
75	Barnes	200	25	Wheeler	1	1,400	3·5	..	..	..	..
77	Guernsey . . .	180	24·2	Cole Marchent	..	1,000	..	..	..	..	..
84	W. H. Booth on "Condensing Plant," *Cassier Mag.*, Oct.-Nov. 1904 .	..	..	..	..	..	..	..	..	..	10

TABLE CXI.—RELATIVE ECONOMY[1] OF 28 INCHES VACUUM OVER 26 INCHES 2000 K.W. PLANT, £800 INCREASED COST, DUE TO RAISING VACUUM FROM 26 INCHES TO 28 INCHES.

Net Saving expressed as Percentage of Increased Capital Cost to secure 28in. Vacuum over that for 26in. Vacuum.	Average Load in K.W.	Hours of Service per Day.	Actual Evaporation, Lbs.	Steam Consumed, average Lbs. per K.W.H.	Water Saved by raising Vacuum 26in. to 28in. Lbs. per K.W.H.	Coal, Shilling per Ton.
118	1500	24	9·5	23	1·84	18
27	1000	24	8	22	1·76	9
4	1000	10	8	22	1·76	4·5

[1] *Report of American Street Railway Association*, p. 179, Oct. 1904, Mr J. R. Bibbins, "Steam Turbine Power Plants." Five per cent. interest and 7·5 per cent. depreciation on extra cost of condenser equipment, 0·5 penny per K.W.H. extra power consumed, are charged, and fivepence per 1000 gallons for feed water saved is credited.

—continued.

Item Number.	Vacuum.		Air Pumps.	Circulating Pumps.			Percentage of Rated Output of Main Generator used by		
	Inches.	Barometer.	Power consumed at Rated Full Load. Power to Air Pumps.	Head, including Friction, Feet.	Gallons per Minute Rated.	Power consumed at Rated Full Load.	Air Pump.	Circulating Pump.	Lift Pump.
80	27·25	29·1	..	(?)	670	6·6 K.W.	..	..	..
81	24	..	..	..	1,050	..	..	..	..
„	24	..	..	..	760	..	..	..	..
82	28	..	12 K.W.[1]	17	..	..	..	2·4	
55	25	30	12 K.W.[1]	4	..	..	..	2·4	
20	28	29·75	..	6	..	..	..	..	
17A	..	..	..	..	..	..	..	..	
74	25 to 26	..	.	7	..	..	..	10	
75	25	..	..	15 to 30 tidal	..	..	..	..	
	24	30	..	40	..	13 K.W.	..	..	
	..	..	..	..	..	..	..	..	

[1] One motor drives both air and circulating pumps.

It is not clear why the lower average load (1000 kilowatt) is credited with 1 lb. per K.W.H. better steam consumption than the 1500 kilowatt load in Table CXI.

The fact that with very cheap coal there is a price where the saving becomes zero was brought out, and values plotted, the change from gain to loss in the three cases mentioned in Table CXI. being at 1·6, 2·6, and 5·7 shillings per ton respectively.

Naturally, all the conditions of each prospective plant must be studied carefully in order to design the plant best suited for those conditions.

[Table CXII.

TABLE CXII.—COOLING TOWERS WITH CONDENSER OF RATED CAPACITY.

Lbs. of Steam per Hour Condensed.		Tower Dimensions.			Weight.	Fans.			Data from
	H.P. of Engine.	Length.	Breadth.	Height.		Number.	Diam.	*Power* to drive H.P.	
		ft.	ft.	ft.	tons.		ft.		
1,000	45	4·25	3·25	30·25	4·5	1	3	1·5	W. H. Booth, *Cassier*, Oct. 04.
15,000	1000	10	12·25	39·5	17	2	8	14	,,
30,000	2000	14	16	40	27	2	10	24 max.	,,
..	14,000 K.W.	25,422	sq. ft. tank	78	..	none	30° F.	..	T. Sugden & Co. London.[2]
25,000	..	30ft. diam.		85ft.	..	none			Charing Cross Co.'s Bow Plant.
..	..	..		38ft. to water delivery	..	..			..
400,000[1]	18,000 K.W.	18,000 sq. ft.		..	..	..			Charing Cross Co's. Bow Plant.

[1] This assumes 16 towers total. The drawing in *Proc. Inst. Electrical Engineer*, Dec. '05, is unfinished.

[2] Messrs T. Sugden & Co. rate the Neasden plant at 1,600,000 gallons, cooled per hour in the height of summer from 110° F. to 80° F., giving with the condensing plant installed 27 inches vacuum at normal load and 26 inches at maximum load. See items 67 to 70A, "Neasden," and Fig. 404, p. 560.

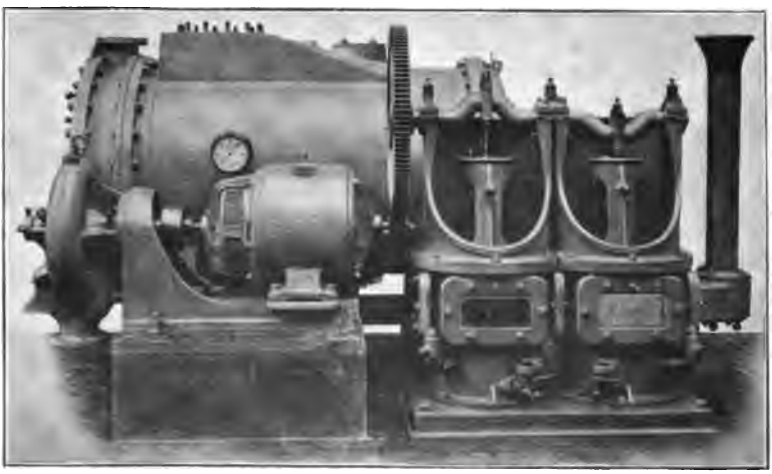


FIG. 334.—Surface Condenser Plant at Partick, 18,000 *Lbs. per Hour*, 2300 *Sq. Ft. Test in Table CX.* (79), p. 432.

(*Mirrlees Watson Co., Glasgow.*)

Fig. 334 shows the Mirrlees Watson surface condenser, with one motor driving both air pump and circulating pump, installed at Partick. The makers kindly supplied test results stated in Table CX.

TABLE CXIII.—MARINE CONDENSERS: CONDENSER SURFACE AND BOILER SURFACE IN SOME VESSELS EQUIPPED WITH STEAM TURBINES.

Name of Vessel.	Condenser Surface: sq. ft.	At Speed: Knots.	Steam per hour.		Ratio: *Condenser Surface to* Boiler Heating Surface.	Ratio: *Boiler Heating Surface to* Grate Area.	*For further data see page 630.*
			Lbs.	Lbs. per sq. ft. of Condenser			
"Turbinia 1st" .	4,200	31	27,000	6·4	3·8	26	
"Viper" . .	8,000	...	191,000	24	0·53	55	
"Cobra" . .	8,000	...	...	...	...	...	
"Queen Alexandra"	...	...	66,000	...	...	...	
"Revolution" .	2,200	...	32,600	15	...	...	
"Tarantula" .	...	...	...	...	...	51	
"Lorena" . .	...	...	...	...	...	40	
"Amethyst" .	...	...	190,000	...	...	53	
"No. 1125" . .	...	...	...	...	...	51	
"No. 293" . .	...	...	...	...	...	47	
"Lubeck" . .	5,380	...	...	...	...	...	
"Turbinia 2nd" .	...	18	58,000	...	...	37	
"Manxman". .	8,820	23	173,000	20	0·71	31	
"Londonderry" .	7,400	22	136,000	18	0·60	31	
"Virginian". .	...	...	...	...	...	42	
"Caroline" . .	...	...	...	...	...	51	
"Carmania". .	32,400	...	...	...	0·66	41	
"Victorian". .	17,000	19	...	...	0·55	39	

It will be noted that of the few turbine vessels whose rate of condensation per square foot of surface is stated in Table CXIII., only the "Viper" approaches to the figure stated as "ordinary marine practice" in Table CXIV.

In the turbine set installed at Fulham, illustrated by courtesy of Mr A. J. Fuller, on page 558 (Fig. 402), the condenser, which is of the subbase type, is set out of sight below the engine-room floor level.

Some details and illustrations of the condensers in use at Lots Road, Chelsea; Neasden; Carville; Delray, Detroit; L. Street, Boston; Quincy Point; Yoker; Motherwell; Thornhill; Radcliffe; Brimsdown; and English M'Kenna Co. are included in Chapter XXII., pp. 454–629.

There are also references to pages containing illustrations in connection with the different types of turbine described in the earlier chapters of this book at the end of this chapter (on p. 440).

It is of interest here to indicate the range of experiments described in Mr R. W. Allen's paper on "Surface Condensing Plants," read before the Institution of Civil Engineers, February 28, 1905, by the following brief notes on it and on the discussion.

TABLE CXIV.

	Lbs. of Steam Condensed per Hour per Sq. Ft. of Condenser Surface.	Air Pump Capacity.		Vacuum maintained. Inches of Mercury.
		Volume per 1 Lb. of Steam Condensed.	Ratio of Volume to Volume of Condensed Steam.	
Mr R. W. ALLEN'S 800 sq. ft. condenser:				
Experiments with engine	..	..	..	5 to 25
" without engines	5 to 10	..	..	..
Cooling water used 40 to 120 times the weight of steam	..	{ 0·5 3·0 }	..	..
"In United States with very large turbines, 2-stage air pump"	..	2 cu. ft.	..	.
Mr Allen's own equally good results with single-stage air pump	..	0·75 cu. ft.	..	..
Mr W. J. HARDING had under notice single-acting air pump	20	0·35	..	26·5
Three throw air pump, 1000 sq. ft. condenser	10	0·63	..	29 (30" Barom.).
"Mr Allen's rule"	9 to 10	0·6 to 0·75	19 to 23	..
Ordinary Marine Practice as much as (See also Table CXIII.)	25	..	..	..
Claimed for concentric condenser	70	..	..	..
Admitted for concentric condenser	35	..	..	good
Mr W. H. PATCHELL:				
Everyday work of condenser with cooling tower 30 ft. diam. on roof dealing with steam from 800 K.W. engine. (Pumps use 8·5 per cent., fans use 2·5 per cent. of main engine input).	6	..	..	..
Large-steam turbine he had inspected.	7·5	..	..	..

Mr FRED. EDWARDS disagreed with the usual velocity of water through tubes, viz., 200 to 300 feet per minute.

He mentioned that the mercury gauge reads 0·25 inch at absolute vacuum, while his own design of gauge reads correctly.

Mr HARVEY E. MOLÉ prefers 2-stage dry-air pump to wet-air pump.

He quoted the specification of N.Y.C. & H.R.R. Co. for "2-stage" dry-air pumps, guaranteed hotwell water within 1° F. of the temperature corresponding with the vacuum in the condenser.

He stated that Lots Road, Chelsea, and Neasden have dry air-pumps, and water is taken out practically as hot as the vaporised steam.

Figs. 335 and 336 show to scale the 3000 K.W. Willans &

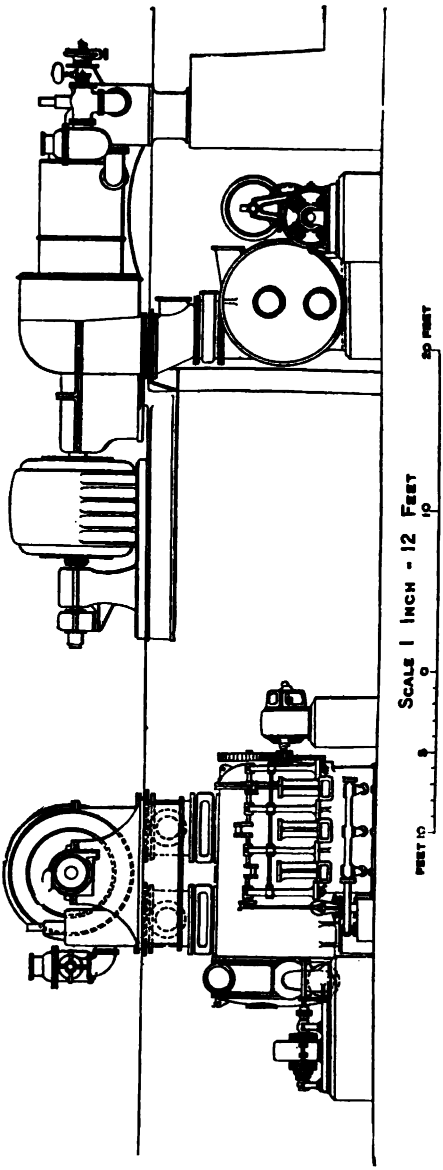


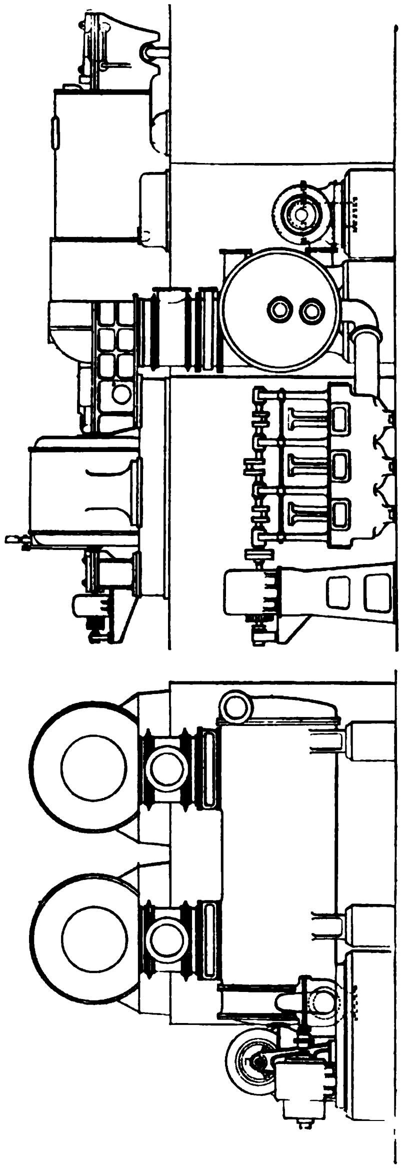
FIG. 335.—Port Dundas, Glasgow.

Willans & Robinson, Parsons Turbine 3000 K.W. Generator. Allen, 11,000 Sq. Ft. Surface Condensing Plant.

(*Proc. Inst. Civil Engrs.*)

Robinson Parsons turbine, D.K. generator, and Allen 11,000 sq. ft. surface condensing plant, at Port Dundas, Glasgow, and

two 1000 K.W. Parsons-Peebles sets, with one Allen condenser (4400 sq. ft.), at Poplar, London.



SCALE 1 INCH = 8 FEET

FOOT 1 0 1 2 3 4 5 10 FEET

FIG. 386.—Poplar, London. Two Parsons-Peebles 1000 K.W. Turbo-Generators, with one Allen 4400 Sq. Ft. Surface Condensing Plant (see p. 6).

(*Proc. Inst. Civil Engrs.*)

Other condensers are illustrated in connection with turbines on pages 207, 224, 252, 286, 314.

CHAPTER XIX

FOUNDATIONS

THOUGH some advocates[1] of the steam turbine would have this subject passed over as unimportant, the foundations in the elevation of nearly every turbine plant that has been built are a very prominent feature.

Mr E. H. Sniffin, of Messrs Westinghouse, Church, Kerr & Co., put forward[2] curves of the cubic yards and cost of foundations for various arbitrary combinations of steam generating units. Fig. 337 and Table CXV. compare his foundations with those of a few recent steam turbo-generators. Mr Sniffin's results are here reduced to the volume for one steam-driven unit, this being a practical basis.

Messrs Willans & Robinson's foundations for two 1000 K.W. turbo-generators are of interest in the following table. As stated there, the turbine and condenser occupy the same position in plan. We have taken the liberty of assuming 3 feet depth of turbine foundation below the basement floor on which the condensers stand, but have not included the foundation under the condenser. The weight of condenser plant is, however, included, as noted, but its effect on the pressure per square foot is small.

The Central London Railway Allis horizontal cross compound-engine foundation naturally meets Mr Sniffin's curves. The

[1] The following extract is not justified by any turbine we have seen :—"As is well known, the absence of any kind of vibration or external thrust permits the employment of any kind of foundation of sufficient strength to sustain the dead weight."—J. R. Bibbins, p. 187, Report, American Street Ry. Assn., Oct. 1904.

[2] American Street Railway Association, Report of Meeting, Oct. 1902, at Detroit, p. 182. The price in America for concrete foundations laid was given as $7, about 29 shillings, per cubic yard.

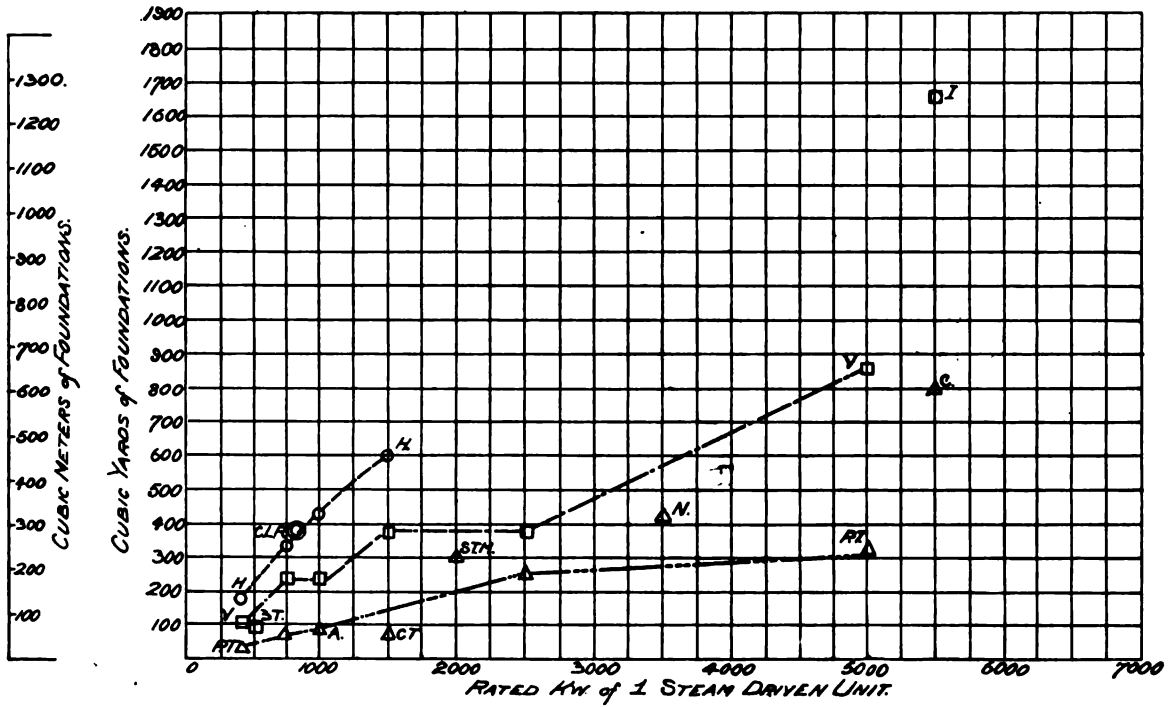


Fig. 337.—Volume of Foundations for Turbines and Reciprocating Units.

H V, Sniffin's curves for cross compound Corliss engines and direct-connected generators, H = horizontal and V = vertical engines.
P T, Sniffin's curves for Parsons turbo-generators.
C L R, Central London Ry. horizontal cross compound 96 R.p.m., Allis 850 K.W. set.
S T, Willans-Parsons vertical reciprocating set.
A, " " turbine set at Avonbank, Bristol
St M, (Approximate) Parsons turbo-generator.

N, Neasden, Westinghouse-Parsons: incorrectly set one space too high. (See Table CXV.)
I, Interborough (Subway) horizontal and vertical reciprocating.
C, Chelsea turbines.
C T, Yorkshire Power Co. vertical Curtis turbine.

Circles show horizontal reciprocating sets.
Squares show vertical reciprocating sets
Triangles show turbines.

TABLE CXV. FOUNDATIONS OF STEAM-DRIVEN GENERATORS (TURBINES AND RECIPROCATING). SEE FIG. 337.

	Type of Turbine or *Engine*.	Rated Output of Unit.	Foundations. Length.	Foundations. Breadth.	Foundations. Area.	Foundations. Depth.	Volume. Cubic Yards per K.W. Horiz.	Volume. Cubic Yards per K.W. Vertic.	Volume. Cubic Yards per K.W. Turbine.	Volume. Total Cu. Yds.	Weight. Tons of Concrete.	Weight of Machine. Tons (2240 lbs.).	Pressure on Subsoil. Tons per Sq. Ft.
			ft.	ft.	sq. ft.	ft.							
Essen	Brown-Boveri-Parsons Turbine	1500	65	8·5	..	..	..	..	..	..	..	190	..
	Foundation	..	..	..	..	..	..	..	..	..	..	..	..
Chelsea, Lots Rd.	Westinghouse-Parsons Turbine	5500	48	11·3	598	..	..	..	..	..	..	248	1·9
	Foundation	..	50	15	750	39	..	..	0·15	800	1200	..	..
Interborough R. T. (Subway)	75 R.p.m. 4 *Cylinder Vert. and Horiz. Reciprocating*	*5500*	..	..	..	..	..	..	..	..	..	*206*	..
	Foundation	..	*55*	*40 overall*	*1950*	*30*	*0·24*		..	*1650* [1]	*2500*	..	*1·4*
For Comparison: Mr Sniffen's Estimate	*Recip. Vertical*	*5000*	..	..	..	*15*	..	*0·17*	..	*850*	..	..	..
	Turbine	,,	..	..	..	15	..	..	0·06	350	..	..	..
Neasden	Westinghouse-Parsons Turbine	3500	..	..	547	..	..	..	..	..	..	218	1·8
	Foundation	..	41·5 [2]	12	..	22	..	..	0·12	300	450	..	..
For Comparison: Mr Sniffen's Estimate	*Recip. Vertical*	2500	..	..	..	15	..	0·14	..	370	..	..	..
	Turbine	,,	..	..	..	15	..	..	0·10	250	..	..	..
Vienna Reciprocating	*Sulzer 4 Cyl. Triple Ex.*	*2000*	..	..	..	..	..	..	..	..	..	*245 Engine only*	..
St M., approximate	Parsons Turbine	3000	..	..	..	..	..	..	..	..	..	..	..
	Foundation	..	..	..	450	18	..	..	0·15	300	450	..	1 approx.
Yorkshire P. Co.	Curtis Turbine, 1500 R.p.m.	1500	..	..	..	..	..	..	..	..	..	46·5	1·8
	Foundation	3	11·5	11·5	112	15·2	..	..	0·04	63	95	..	..
For Comparison: Mr Sniffen's Estimate	Recip. Horiz.	1500	..	..	..	15	0·40	..	..	600	..	..	..
	,, ,,	1000	..	..	..	15	0·42	..	..	425	..	..	..
	,, Vertical	,,	..	..	..	15	..	0·22	..	225	..	..	..
	Turbine	,,	..	..	..	15	..	..	0·08	80	..	..	..
Willans & Robinson's Avonbank E. W. (6047B)	**Parsons Turbine**	1000	..	..	..	..	..	..	..	..	..	40 [5]	..
	Foundation	..	..	..	125	15·2 [4]	..	..	0·07	74	111	..	1·2
Central London Ry.	*Allis Horiz. Recip. 96 R.p.m. Cross Compd.*	*850*	..	..	..	..	..	..	..	..	..	..	..
	Foundation	..	*35·5*	*27·5*	*563*	*15* [6]	*0·44*	..	..	*376*	565	..	..
For Comparison: Mr Sniffen's Estimate	Recip. Horiz.	750	..	..	..	15	0·49	..	..	370	..	..	..
	,, Vertical	,,	..	..	..	15	..	0·31	..	230	..	..	..
	Turbine	,,	..	..	..	15	..	..	0·09	66	..	..	..
Willans & Robinson (8698)	*'3 T' Recip. Vert.*	*500*	..	..	..	..	..	..	..	..	..	*Engine 37*	*About 0·8*
	Foundation	..	*26*	*9 & 12*	*270*	*9*	..	*0·17*	..	*87*	*130*	..	..
For Comparison: Mr Sniffen's Estimate	Recip. Horiz.	400	..	..	..	15	0·44	..	..	175	..	..	..
	,, Vertical	,,	..	..	..	15	..	0·25	..	100	..	..	..
	Turbine	,,	..	..	..	15	..	..	0·06	25	..	..	..

1 This has been stated as 1320, which may exclude generator foundation or not go to rock bottom. Scaling the drawing in *Engineering*, Feb. 3, 1905, to bottom of concrete, gives the above foundation dimensions, which show 1400 cu. yards for the two parts of engine, and 250 cu. yards for generator foundation.
2 Approximate.
3 Drawings with no scale, *Power*, p. 69, E, Aug. 1904; *Electrical Power*, Nov. 1904. *Electrical Review*, Sept. '05.
4 We assume 3ft. depth below basement floor level. The condensers are immediately below the turbines, *i.e.* occupy same position in plan.
5 Including condensing plant.
6 The drawing, 'Traction and Transmission,' 1903, shows 2ft. 9in. depth below basement floor level.

Interborough (Subway), New York, 4 cylinder-engine foundation should, of course, lie above the curve V and below H, if H were plotted so far. The vertical turbine CT falls well below the Parsons, while Chelsea, equipped with vertical condenser and Westinghouse-Parsons sets, is considerably above Mr Sniffin's estimates for turbines.

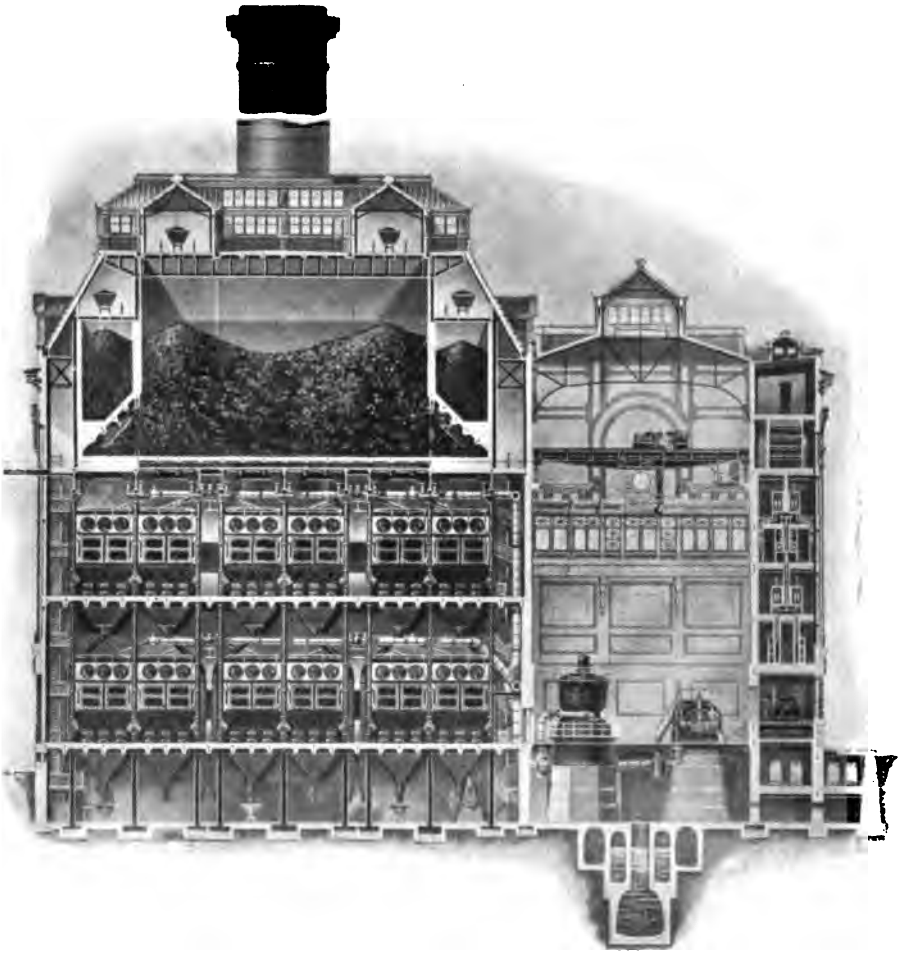


FIG. 337A.—Section through New York Edison Co.'s New 80,000 K.W. Waterside Station (No. 2). See also pages 455, 481, and 491.

Approximate scale 1 : 570.

CHAPTER XX

BUILDINGS

The areas and volumes of engine-rooms and boiler-houses are given below, taking first those steam turbine plants on which data has been secured, then some mixed plants, and finally some reciprocating engine plants. The item numbers correspond with those in Tables CIII., CIV., p. 424, on pressure, superheat, and vacuum in use in the same plants.

In every case where the ultimate capacity of present buildings is known the useful figures are based on it, but in other cases the size per kilowatt installed is the best that is available.

This table is intended for use when preparing preliminary estimates, as one can form from it a very definite idea, based on named existing plants, of the dimensions necessary for any probable arrangement of generating units.

Plans of sites of some recent turbine plants are shown on pages 455, 464 to 467.

Exterior views of seven Power-Houses will be found on pages 468 to 474 (Figs. 343 to 354).

Sections and plans of buildings are on pages 444 and 470 to 490.

TABLE CXVI.—BUILDINGS, AREAS, AND VOLUMES OF SOME STEAM TURBINE PLANTS.

Reference Number.	Name.	Main Generating Units.					Total Rated K.W. installed.	Ultimate Rated K.W. Present Buildings.	Area Boiler-house, sq. ft. per Rated K.W.		Area Engine-room, sq. ft. per Rated K.W.		Volume Boiler-house, cub. ft. per Rated K.W.		Volume Engine-room, cub. ft. per Rated K.W.	
		Number.	Rated K.W each.	R.p.m.	Type.	Power Factor included.			Installed.	Ultimate.	Installed.	Ultimate.	Installed.	Ultimate.	Installed.	Ultimate.
1	Chelsea, Lot Road	8	5,500	...	H	...	44,000	*57,700*	0·76 ground[1]	*0·58*	0·57	*0·43*	118	*90*	64	*49*
1B	New York Edison (No. 2)	4	8,000		V H		31,000	80,000	1·20[2]	*0·46*	0·77	*0·30*	180	*70*	98	*38*
4	Neasden	4 1	3,500 100	...	H	...	14,100	*24,000*	1·22	*0·72*	0·73	*0·43*	...	...	...	...
5	Detroit, U.S.A., Delray	4	3,000	...	V	...	12,000	...	...	...	...	...	...	...	...	...
6	Carville	4	3,500	...	H	...	...	...	...	...	...	...	...	...	...	...
8	Quincy Point	5	2,000	...	V	...	10,000	..	0·94	...	0·9	...	55	...	49	...
9	Boston Edison, U.S.A.	2	5,000	...	V	...	10,000	...	...	...	...	...	...	...	...	...
10	Lancashire P. Co.	4	1,500	...	V	...	6,000	...	...	...	...	...	...	...	...	...
11	Yorkshire P. Co.	3	1,500	...	V	...	4,500	...	...	...	...	...	...	...	...	...
15	Sheffield, Neepsend	2	1,500	...	H	...	3,000	8,000	2·2	*0·84*	2·5	*0·95*	123	*46*	140	*53*
16	Los Angeles, U.S.A.	2	2,000	...	V	...	4,000	...	1·87	...	0·59	...	52	...	26	...
17A	Brimsdown	3	1,000	...	H	...	3,000	...	2·85	..	2·25	...	103	...	72	...
18	English M'Kenna	3	750	...	H	...	2,250	...	...	...	...	...	..	...	...	...
19	Scarborough	2 2 1 1 1	500 300 150 120 75	...	H	...	1,945	...	1·74	...	1·58	...	22	...	29	...
23	Shipley	1 3	450 240	...	H	...	1,170	...	4·5	...	2·4	...	98	...	71	...
27	Yoker, Clyde Valley	2	2,000	...	H	...	...	...	...	...	...	...	...	...	...	...
32	Motherwell	2	2,000	...	H	...	...	...	...	...	...	...	...	...	...	...

H and V indicate horizontal and vertical, R indicates reciprocating, and T turbine driven units.

[1] 1·52 2 floors.

[2] 2·4 sq. ft. floor space.

TABLE CXVII.—BUILDINGS, AREAS, AND VOLUMES OF SOME MIXED TURBINE AND RECIPROCATING PLANTS.

Reference Number.	Name.	Main Generating Units. Number.	Rated K.W. each.	R.p.m.	Type.	Power Factor included.	Total Rated K.W. installed.	Ultimate Rated K.W. Present Buildings.	Area Boiler-house, sq. ft. per Rated K.W. Installed.	Ultimate.	Area Engine-room, sq. ft. per Rated K.W. Installed.	Ultimate.	Volume Boiler-house, cub. ft. per Rated K.W. Installed.	Ultimate.	Volume Engine-room, cub. ft. per Rated K.W. Installed.	Ultimate.
35	Interboro' (Subway), N.Y.	9	5,000	...	V H R	...	48,750	*67,500*	1·05	*0·95*	0·75	*0·69*	105	*95*	75	*69*
		3	1,250	...	H T	...										
36	Manhattan Elevated, N.Y.	8	5,000	...	V H R	...	40,000	...	2·06	boiler &	engine	...	...	215	boiler &	engine
37	Manchester, Dickinson St.	2	3,750	...	V R	...	34,300	...	1·97	...	1·48	...	103	...	108	...
		4	1,800	...	,,	...										
		8	1,500	...	,,	...										
		2	750	...	,,	...										
		4	250	...	,,	...										
		2	*1,800*	...	H T	...										
		2	750	...	,,	...										
12	Neptune Bank, Newcastle .	1	1,500	...	H T	...	4,700	...	1·5	...	1·5	...	...	...	...	...
		4	700	...	V R	...										
13	Halifax	2	750	...	H R	...	4,600	.	2·3	...	2·6	...	...	...	...	...
		3	700	...	V R	...										
		2	300	...	H R	...										
		2	200	...	H T	...										
20	*Harrogate*	1	750	...	V T	...	1,900	...	0·74	...	1·58	...	53	...	66	...
		1	300	...	H T	...										
		2	300	...	R	..										
		2	125	...	R	...										
22	*Middlesboro'* . . .	1	600	...	H T	...	1,600	...	2·9	...	2·5	...	64	...	74	...
		2	300	...	R	...										
		1	100	...												
24	*Kidderminster* . . .	2	300	...	H T	...	900	...	...	...	...	...	...	...	...	...
		3	100	...	V R	...										
41	Kansas City, Met. S.R. Co.	3	3,000	...	V R	...	14,000	89,000 turbine extensions	3·3	*1·2*	1·8	*0·66*	150	*54*	200	*70*
		1	5,000	...	T	...										

TABLE CXVIII.—BUILDINGS, AREAS, AND VOLUMES OF SOME RECIPROCATING PLANTS.

Reference Number.	Name.	Main Generating Units.					Total Rated K.W. installed.	Ultimate Rated K.W. Present Buildings.	Area Boiler-house, sq. ft. per Rated K.W.		Area Engine-room, sq. ft. per Rated K.W.		Volume Boiler-house, cub. ft. per Rated K.W.		Volume Engine-room, cub. ft. per Rated K.W.	
		Number.	Rated K.W. each.	R.p.m.	Type.	Power Factor included.			Installed.	Ultimate.	Installed.	Ultimate.	Installed.	Ultimate.	Installed.	Ultimate.
40	Pinkston, Glasgow	4	2500	...	V	...	11,200	...	1·8	...	1·63	engines extra for auxiliaries	128	...	105	engines extra for auxiliaries
		2	600	...	V	...	...	...	...	...	0·87		...	...	44	
41B	Metropolitain, Paris	...	1500	70	H (?)	...	7500	...	2·8	...	2	...	190	boiler and engine		
42	Salford	8	800	100	V	...	...	6400	...	1·9	...	1·5	...	85	...	67
43	West Ham	2	1200	250	V	...	5700	...	3·2	...	2·1	...	...	...	...	...
		2	600	214												
		3	500	180												
		2	300	250												
44A	C. L. Railway	6	850	94	H	...	5200	7000	2·5	1·8	2·7	2	...	...	...	...
		2	50	400	V											
44B	Mersey Railway	...	...	...	V	...	4150	...	2·4	...	2·4	...	...	...	...	...
45	Kelham Is., Sheffield	2	1000	90	V	...	3675	...	2	...	2·5	...	60	...	109	...
		2	500	90	V											
		3	225	134	H											
46	Alpha Place, Chelsea	2	420	300	V	...	3500	...	3·2	...	2·2	...	95	...	50	...
		6	200	330												
		6	150	350												
		7	80	420												
47	Lowell, U.S.A.	1	1600	...	...	...	3500	...	1·2	...	3	...	48	...	91	...
		1	1500													
		1	400													
48B	Midland Power Co.	...	...	...	V	...	3100	...	...	...	4·2	...	...	one stack 9 ft. diam.		

Item 36 belongs in this table. It is in Table CXVII.

49	Dundee	1 1 1 2 2	825 500 450 330 125	...	V	...	3,000	...	2·2	...	2·1	. .	58	...	66	...
50	Paisley	1 2 4	800 500 300	... ...	H V ,,	...	3,000	...	1·9	...	1·8	...	69	...	71	...
51	Wimbledon . . . . 1 phase	1 2 3	625 350 120	300 333 375	V	100	1,685	4,865 turbine extensions	9·2 includes destructor	...	2·7	...	240	...	70	...
52	Reading	3 4	500 250	... ...	,, ,,	...	2,675	...	2·2	...	3·1	...	partly	gas	...	...
53	Ilford	1 2 2 1	1000 550 200 100	...	...	...	2,600	...	1·8	...	1·7	...	43	...	40	...
55	Leicester	1 3	1000 500	80 95	...	...	2500	...	2·8	...	2·8	...	...	...	...	...
56	Wolverhampton . . .	3 1 1 1	500 300 220 140	...	...	...	2,380	4,880	2·7	*1·3*	3·3	*1·6*	53	*26*	107	*53*
57	Greenock	2 2 2 1 1	400 300 170 150 100	...	V	...	2,000	...	2·3	...	2·6	...	61	...	98	...
58	East Ham, London . .	1 1 3	750 500 225	... ...	,, H ,,	...	1,925	...	3·2	...	3·3	...	86	...	98	...
59	Lowestoft	2 1 1 1	500 250 150 75	230 350 330 400	V	...	1,750(?)	...	1·7	...	1·4	...	46	...	37	...

TABLE CXVIII. (*continued*).

Reference Number.	Name.	Main Generating Units. Number.	Rated K.W. each.	R.p.m.	Type.	Power Factor included.	Total Rated K.W. installed.	Ultimate Rated K.W. Present Buildings.	Area Boiler-house, sq. ft. per Rated K.W. Installed.	Ultimate.	Area Engine-room, sq. ft. per Rated K.W. Installed.	Ultimate.	Volume Boiler-house, cub. ft. per Rated K.W. Installed.	Ultimate.	Volume Engine-room, cub. ft. per Rated K.W. Installed.	Ultimate.
		1	500													
		1	450													
60	Burton-on-Trent . . .	1	250		V	85	1,660	..	2·6	...	3·5	...	73	...	104	...
		3	100													
		2	80													
61	Hull Tramways . . .	5	300	...	,,	...	1,560	...	3·2	...	1·9	...	87	...	59	...
		1	60	...	...	...	...	...	0·15	stack	...	...	4	stack	...	...
										extra				extra	...	..
62	Stalybridge	3	500	80	V	...	1,500	3,000	5·5	*2·7*	6·3	*3·1*	112	*56*	304	*152*
		2	320	380	V											
		2	250	400	,,											
63	Burnley	1	160	90	H	...	1500	...	3·3	...	4·2	...	...	*77*	...	130
		2	100	100	,,											
		2	350	350	...	...	1300	...	...	...	...	...	...	...	...	...
64	Walsall	2	200													
		3	45													
		4	250													
65	Bury, Lancs	2	130	...	V	...	1260	...	6·7	...	4·1	..	...	167	...	124
		2	400													
		1	200													
66A	Eastbourne	1	150	..	V	...	1200	...	...	...	...	...	...	...	..	...
		1	50													
66B	North Shore Railway, San	2	400	360	...	...	1200	...	1·9	...	5	...	...	44	...	95
	Francisco	1	400	150												

67	Gloucester	1 1 1 1 1	300 ,, 200 ,, 150	380 360 ,, 340 360	V	...	1150	...	2·5	...	3·1	...	...	88	...	102
68	Kirkcaldy	1 3 2	430 170 45	...	V	...	1030	...	...	...	...	...	...	...	...	...
69	Barrow-in-Furness	2 2 3	250 150 75	...	V	...	1025	...	...	...	...	...	...	...	...	...
70B	Hamilton	...	...	...	H	...	1000	...	3·3	...	5	one stack 7 ft. diam.			...	...
71	Smithfield Market	1 1 3	315 200 150	360 420 135	V	...	965	...	...	...	...	...	...	...	...	...
72	Gillingham	3 1	300 50	...	V	...	950	...	1·6	...	2·8	...	...	49	...	83
73	Carlisle	2 2 2	250 125 60	...	V	...	870	...	5	...	2·3	...	...	120	...	76
74	Chatham	3 1	200 75	... ...	H V	...	675	...	4·1	...	6·3	...	...	260	...	288
75	Barnes	2 2 1	200 35 Battery	420 550	V	...	470	...	4·4	...	3	...	...	117	...	82
76	Worthing	1 3	250 96	400 460	...	...	538	...	...	...	...	...	...	...	...	...
77	Guernsey	2	180	420	V	...	510	...	...	...	...	...	...	...	...	...
	Les Amballes	2	75	500	...	...	...	...	...	...	...	...	...	...	...	...
	St Sampson	2	180	250	gas	...	360	...	...	...	...	...	...	...	...	...
78	Cleethorpes	2	150	200	H	...	300	...	10·7	...	16	...	213	...	480	...

CHAPTER XXI

BOILER AND SUPERHEATER SURFACE INSTALLED

A TABLE of boiler heating surface, grate area, superheater surface, and economiser surface for some of the plants enumerated above is given here.

TABLE CXIX.—BOILER HEATING SURFACE, SUPERHEATER SURFACE, GRATE AREA, AND ECONOMISER SURFACE IN SOME ELECTRICITY PLANTS.

Reference Number.	Name.	Boiler Heating Surface. Sq. ft. per Rated K.W. Installed.	Boiler Heating Surface. Sq. ft. per Rated K.W. Ultimate.	Boiler Grate Area. Sq. ft. per Rated K.W. Installed.	Boiler Grate Area. Sq. ft. per Rated K.W. Ultimate.	Superheater Surface. Degrees F. added.	Superheater Surface. Sq. ft. per Rated K.W. Installed.	Superheater Surface. Sq. ft. per Rated K.W. Ultimate.	Economiser Surface. Tubes.	Economiser Surface. Length.	Economiser Surface. Total.	Economiser Surface. Sq. ft. per Rated K.W. Installed.
1	**Chelsea, Lots Road**	7·7	*7·3*	0·12	*0·11*	150	0·98	*0·93*	9216	10 ft.	..	..
4	**Neasden**	4	..	0·08	..	180	0·63	..	1760	10′ (4″d)	184 sq ft.	..
5	**Detroit, U.S.A.**	9·6	..	..	..	275	..		4992	..	..	..
6	**Carville**	..	..	..	..	150	..	..	..	..	..	..
8	**Quincy Point, U.S.A.**	7·4	..	0 1	..	65	0·14	..	..	..	..	..
9	**Boston Edison**	..	..	..	..	150	1·4?	..	..	..	..	..
10	**Lancashire**	5·7	..	0·1	..	150	0·5	..	..	..	..	..
11	**Yorkshire**	5·7	..	0·1	..	150	..	..	..	..	..	..
12	Neptune Bank, Newcastle	6·1	..	..	..	..	..	..	..	..	..	..
13	**Halifax**	48	..	0·07	..	..	..	..	..	..	..	..
15	**Sheffield, Neepsend**	4·1	..	0 05	..	..	?	..	..	..	..	..
16	**Los Angeles**	10·	..	oil fuel	..	..	..	..	..	..	..	..
17	**Brimsdown**	8·8	..	..	..	..	?	..	..	..	..	..
18	**English M'Kenna**	..	..	..	..	..	..	..	..	..	..	..
19	**Scarborough**	..	..	..	..	..	..	..	..	..	..	..
20	***Harrogate***	..	..	0·07	..	..	..	..	..	..	..	..
22	***Middlesboro'***	4·6	..	0·15	..	..	zero	..	..	..	..	..
23	**Shipley**	..	..	..	..	..	..	..	..	..	..	..
24	***Kidderminster***	..	..	..	..	..	..	..	..	..	..	..
27	**Yoker**, Clyde Valley	..	..	..	..	136	..	..	..	..	..	..
32	Motherwell	..	..	..	..	..	..	..	..	..	..	..
35	Interboro' (Subway), N.Y.	7·4	*6·4*	0·12	*0·10*	..	some	..	..	..	..	..
36	Manhattan Elevated, N.Y.	..	..	0·24	..	..	..	..	..	..	..	..
37	Manchester, Dickenson St.	7·1	..	0·1	..	..	some	..	..	..	..	..
40	Pinkston, Glasgow	7·8	..	0·09	..	..	..	..	..	..	..	..
41	Kansas City, Met. S.R. Co.	..	..	0·2	..	..	some	..	..	..	..	..
41B	Metropolitain, Paris	..	..	..	..	..	..	..	..	..	..	..
42	Salford	..	..	0·12	..	..	some	..	..	..	..	..
43	West Ham	14·6	..	0·2	..	..	some	..	..	..	..	..
44A	C. L. Railway	11	*10·2*	0·28	..	..	none	..	..	..	..	..

TABLE CXIX.—*continued.*

Reference Number.	Name.	Boiler Heating Surface. Sq. ft. per Rated K.W. Installed.	Boiler Heating Surface. Sq. ft. per Rated K.W. Ultimate.	Boiler Grate Area. Sq. ft. per Rated K.W. Installed.	Boiler Grate Area. Sq. ft. per Rated K.W. Ultimate.	Superheater Surface. Degrees F. added.	Superheater Surface. Sq. ft. per Rated K.W. Installed.	Superheater Surface. Sq. ft. per Rated K.W. Ultimate.	Economiser Surface. Tubes.	Economiser Surface. Length.	Economiser Surface. Total.	Economiser Surface. Sq. ft. per Rated K.W. installed.
44B	Mersey Railway	..	..	..	..	..	..	..	..	..	..	..
45	Kelham Is., Sheffield	4·5	..	0·1	..	..	some	..	..	..	..	..
46	Alpha Place, Chelsea	13 non-condensed	..	0·21	..	..	none	..	..	..	..	..
47	Lowell, U.S.A.	7·4	..	0·09	..	..	none	..	..	..	..	..
48B	Midland Power Co.	..	..	..	..	..	..	..	..	..	..	..
49	Dundee	4·5	..	0·16	..	..	..	..	..	..	..	..
50	Paisley	6·4	..	0·09	..	..	..	...	..	..	..	..
51	Wimbledon	11·6 destructor	..	0·24	..	..	some	..	..	..	..	..
52	Reading	3·7	..	0·11	..	..	..	..	..	..	..	..
53	Ilford	5·6	.	0·13	..	..	..	..	..	..	..	..
55	Leicester	2·8	..	1·1	..	..	none	..	.	..	..	..
56	Wolverhampton	3·9	..	0·13	..	..	..	..	.	..	..	..
57	Greenock	5·5	..	0·25	..	..	..	..	..	..	..	..
58	East Ham, London	15	..	0·29	..	..	..	..	..	..	..	..
59	Lowestoft	4·1	..	0·08	..	..	some	.	..	..	..	..
60	Burton-on-Trent	3·7	..	0·08	..	..	none	..	..	..	..	..
61	Hull Tramways	3·1	..	0·1	..	..	none	..	..	..	..	..
62	Stalybridge	5·1	..	..	..	..	none	..	..	..	..	..
63	Burnley	5×28′×7′ d Lancs 2×30′×8′ d Lancs	..	..	..	..	none	..	..	..	..	..
64	Walsall	..	..	..	..	..	none	..	..	..	..	..
65	Bury, Lancs	3·6	..	0·15	..	..	some	..	..	..	..	..
66A	Eastbourne	8·7 non-condensed	..	0·18	..	..	some	..	..	..	..	..
66B	North Shore Railway, San Francisco	6·6 crude oil	..	..	..	..	..	..	..	..	..	..
67	Gloucester	5·9	..	0·26	..	..	some	..	..	..	..	..
68	Kirkcaldy	10·6	..	0·18	..	..	none	..	..	..	..	..
69	Barrow-in-Furness	..	..	..	..	..	some	..	..	..	..	..
70B	Hamilton	..	..	..	..	..	..	..	..	..	..	..
71	Smithfield Market	6·7 non-condensed	..	..	..	..	none	..	..	..	..	..
72	Gillingham	6	..	0·12	..	..	some	..	..	..	..	..
73	Carlisle	5	..	0·21	..	..	none	..	..	..	..	..
74	Chatham	5·9	..	0·13	..	..	none	..	..	..	..	..
75	Barnes	10·2	..	0·21	..	..	some	..	..	..	..	..
76	Worthing	5·6	..	..	..	..	none	..	..	..	..	..
77	Guernsey, Les Amballes	14	..	3	..	..	some	..	..	..	..	..
	St Sampson	..	..	..	..	..	..	..	..	..	..	..
78	Cleethorpes	5·5	..	0·24	..	..	none	..	..	..	..	..
	New York Edison, Waterside No. 2	..	7·8	..	0·15	100	..	1·2	..	..	..	..

CHAPTER XXII

EXAMPLES OF STEAM TURBINE PLANTS

THE following pages contain a digest of essential details of a number of the latest steam turbine plants.

This listing of corresponding parts of plants in parallel columns (starting from the coal pile and advancing to the kilowatt) is commended to students as of value, because it facilitates reference to the details which everyone concerned in arranging such plants must study and compare.

In the Preface will be found acknowledgment of the assistance rendered in the collection of this data, and a considerable part of it and many of the illustrations are from the valuable technical papers to which credit is given.

The compilers venture to think that if technical papers would adopt such a standard outline instead of, or supplementary to, the usual text descriptive of new plants, that their readers would appreciate and derive more benefit from the data. It would be essential to reproduce each time the same spacing of the outline form to permit immediate comparisons by placing the new data alongside the earlier collection.

The plants included here are Lots Road, Chelsea; Neasden; Carville; Delray, Detroit; L. Street, Boston; Quiny Point; Yoker; Motherwell; Thornhill; Radcliffe; Brimsdown; and English M'Kenna Co.

The New York Edison Company's New Waterside Station is illustrated, by the courtesy of the *Power* Publishing Co., on pages 444, 455, and 481. The capacity of this station will be 31,000 K.W., with ultimate capacity, with present sizes of units, of 80,000. These units, mentioned on pp. 147 and 209, are the largest that have been undertaken.

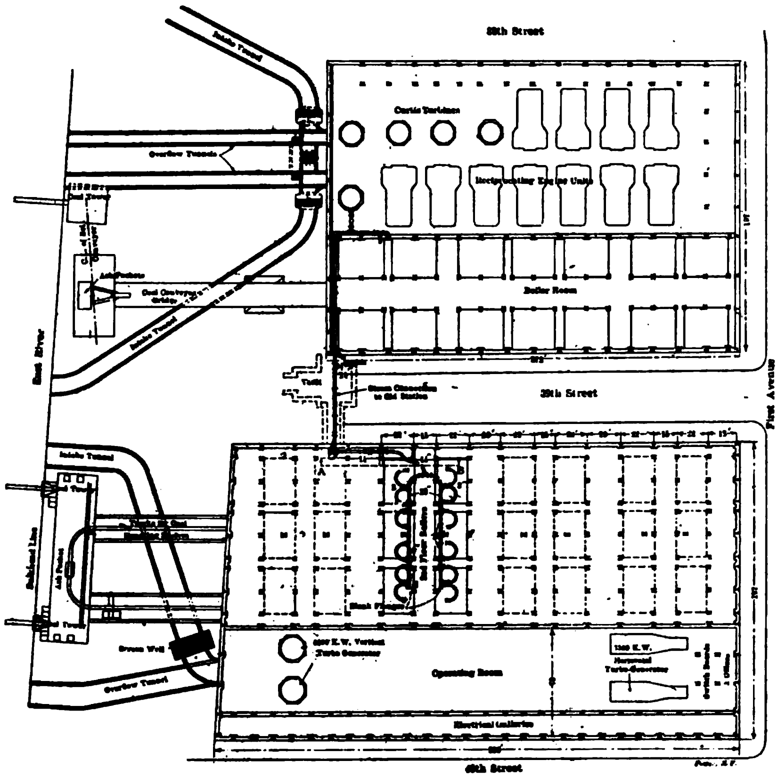


FIG. 337B.—New York Edison Co.'s Plan of Old and New Waterside Stations. See also pp. 444, 481, and 491.

The Waterside No. 1 Station between 38th and 39th Streets (at the top of this figure) contains eleven reciprocating units and five 5000 K.W. Curtis Turbines: 70,000 K.W. total.

The Waterside No. 2 Station between 39th and 40th Streets (lower part of figure) has room for 80,000 K.W.

1. **Name of Generating Station** .	**Lots Road, Chelsea.**
2. Cost per *ultimate* rated K.W. capacity	£44. £2,500,000 for 57,000 K.W.[1]
3. Owners	Underground Electric Rys. Co. of London, Ltd.
4. Location	Chelsea, London. Fig. 338.
5. Area	3·67 acres.
6. Frontage	824ft. Lots Road, Chelsea; 1100ft. on the River Thames and Chelsea Creek.
7. Supply to Consumers . .	11,000 volts, 3 phase, 33⅓ cycles, to 24 substations; 600 volts continuous substations.
8. Consumers	Metropolitan District Railway; Baker Street and Waterloo (Tube) Railway; Charing Cross and Hampstead (Tube) Railway; Edgeware and Hampstead (Tube) Railway.
9. Buildings	Figs. 343, 344, p. 468.
10. Foundations	35ft. below Lots Road.
Piers	220 of concrete.
11. Type of Structure . . .	6000 tons of steel frame. Brick and terra-cotta panelled.
12. Maker of Frame . . .	British Westinghouse Co.
13. Erection by	Mayoh & Haley (the Fulham Steel Works Co.).
14. Wharf Wall	Portland cement faced with Staffordshire blocks.
Length and Height . .	980ft. long, 30ft. high.
15. Plan of Buildings . . .	See Fig. 351, p. 471.
16. Dimensions	453½ft. long by 175ft. wide.
17. Boiler-house	100ft.
18. Engine-room	75ft.
19. Transformer H.	
20. Height	140ft. high to peak of boiler-house roof.
21. Sectional Elevation of Buildings	See Fig. 350, p. 470.
22. Roof-glazing	'Eclipse,' by Mellowes & Co., Ltd., Sheffield.
23. Basement Floor . . .	18ins. above highest recorded tide; 3 feet below the level of Lots Road; 19ft. head room: 3 parts: 2 for ashes, middle for pumps.
24. Floors of Boiler-room . .	Concrete and expanded metal.
Walls of Boiler-room . .	,, ,, ,,
25. Floor of Switchboard Galleries .	
26. Floor of Engine-room . .	Checkered steel plates.
Walls of Engine-room . .	
27. Staircases	of steel to bunkers at each chimney.
28. Electric Lift	Basement to the second boiler-room floor.
29. Delivery of Coal to Power-house, one end	*At West End* by Railway. West London Extension Railway runs over hoppers on opposite side, Chelsea Creek. An inclined bucket conveyor will be erected to span the creek.

[*Continued on p.* 492.

[1] *Electrical Review*, June 9, 1905, p. 938. 24 substations and 300 miles of cable presumably included. Power-house probably under £30 per K.W.

1.	**Neasden.**	**Carville.**
2.		
3.	Metropolitan Railway Co.	Newcastle-upon-Tyne Electric Supply Co., Ltd.
4.	Neasden, London, N.W.	Carville. Fig. 339.
5.	3570 square yards.	
6.		
7.	550 volts continuous current from 9 substations, 11,000 volts, 3 phases, 33⅓ cycles.	6000 volts, 3 phases, 40 cycles. 600 volts continuous current from 5 substations.
8.	Metropolitan Railway Company and Branches.	37 miles double track, North-Eastern Ry.
9.	Fig. 345, p. 468.	
10.	8ft. deep by 11ft. 6in. wide, concrete.	
11.	Engine-house, red brick and buff terra-cotta; boiler-house, steel and red brick.	Steel frame, filled in with corrugated iron.
12.	Heavy work by Hein, Lehman & Co., details by Dorman & Long.	
13.	British Westinghouse.	
14.	None.	
15.	See Fig. 358, p. 473.	Fig. 355, p. 475.
16.	324ft. long by 101ft. wide.	
17.	53ft. by 321ft.	
18.	Engine-room, 233¾ft. by 43½ft.	
19.	Transformer house, 66ft. by 43½ft.	
20.	45ft. basement floor to bottom chord of roof truss.	
21.	See Fig. 353, p. 472.	
22.	Mellowes & Co., Ltd.	
23.	Concrete, with 2in. of granolithic surface.	
24.	Blue bricks.	
25.	Concrete and expanded metal.	
26.	Concrete and mosaic, the main generators resting on brickwork jack-arches.	
27.	Of steel.	
28.		
29.	At south end: Siding of Metropolitan Railway, running over hoppers.	By N.E. Ry. Co. An overhead siding (1 in 25 grade), conveyed by electric locomotive, two 75 horse-power Westinghouse 500 volt motors. 4 M.P.H. Overhead conductor; Bow collector.

[*Continued on p.* 493.

1. Name of Generating Station	**Delray, U.S.A.**
2. Cost per *ultimate* rated K.W. capacity	
3. Owners	**Detroit Edison Co.**
4. Location	**Delray, 3½ miles from Detroit, Mich.**
5. Area	**39 acres. Fig. 340, p. 466.**
6. Frontage	
7. Supply to Consumers	
8. Consumers	Edison Illuminating Co. ; Peninsular Electric Light Co. ; Detroit United Railways.
9. Buildings	**Fig. 346, p. 468.**
10. Foundations	
Piers	
11. Type of Structure	**Steel frame, brick panelled.**
12. Maker of Frame	
13. Erection by	
14. Wharf Wall	
Length and Height	
15. Plan of Buildings	**Two boiler-rooms, separated by a fire wall, and one turbine-room. Fig. 356, p. 476.**
16. Dimensions	
17. Boiler-house	158ft. wide, 162ft. long.
18. Engine-room	51ft. wide, 179ft. long.
19. Transformer H.	
20. Height	
21. Sectional Elevation of Buildings	Figs. 357 and 358, p. 477.
22. Roof-glazing	
23. Basement Floor	Reinforced concrete.
24. Floors of Boiler-room	
25. Floor of Switchboard Galleries	
26. Floor of Engine-room	
Walls of Engine-room	
27. Staircases	
28. Electric lift	
29. Delivery of Coal to Power-house, one end	By rail to a coal tower farthest from the river. In this tower, coal is hoisted, crushed, and screened.

[*Continued on p.* 494.

1.	**L. Street Station, Boston, U.S.A.**	**Quincy Point, Mass., U.S.A.**
2.		
3.	Boston Edison Electric Illuminating Company.	Old Colony Street Railway Co.
4.		Quincy Point, about eight miles south of Boston.
5.	Fig. 341, p. 467.	
6.		
7.		13,200 volts current, 25 cycles, 3 phase, to 6 substations (provision for 3 additional).
8.		Owners' tramway system. 400 miles.
9.		
10.	Support 4000lbs. per sq. ft.; 520,000lbs. includes condenser, total weight one unit.	
11.		
12.		
13.		
14.		
15.	Fig. 359, p. 478.	Fig. 362, p. 482.
16.		161ft. by 121ft., divided by a brick wall.
17.	150ft. by 150ft. boiler-room (built 1905).	161ft. by 60ft.
18.	220ft. by 68ft. engine-room (built 1905).	161ft. by 60ft.
19.	650ft. by 218ft. land available to extend.	
20.	Boiler ceiling 35 ft. high.	
21.	Figs. 360, 361, p. 479.	Fig. 363, p. 483.
22.		
23.		
24.	Boiler front, white enamel bricks.	
25.		
26.	Dark red tiles; walls 10 feet dark green tiles, 25 feet light tiles above.	
27.		
28.		
29.	By barge; 25ft. depth of water in dock at low tide.	By water. Vessel is unloaded by shears.

[*Continued on p.* 495.

1. **Name of Generating Station** .	**Yoker.**
2. Cost per *ultimate* rated K.W. capacity	
3. Owners	Clyde Valley Electrical Power Co.
4. Location	On bank of River Clyde.
5. Area	
6. Frontage	
7. Supply to Consumers . .	3 phase, 25 cycles, 11,000 volts. (In Clydebank from 2–150 K.W. motor generator sets in first switch gallery.)
8. Consumers	From 2 substations.
9. **Buildings**	Fig. 347, p. 468.
10. Foundations	
Piers	
11. Type of Structure . . .	
12. Maker of Frame . . .	
13. Erection by	
14. Wharf Wall	
Length and Height . .	
15. Plan of Buildings . . .	
16. Dimensions	
17. Boiler-house	186ft. by 50ft.
18. Engine-room	252ft. by 48ft. 6ins.
19. Transformer H. . . .	
20. Height	
21. Sectional Elevation of Buildings	
22. Roof-glazing	
23. Basement Floor . . .	
24. Floors of Boiler-room . .	
Walls of Boiler-room . .	
25. Floor of Switchboard Galleries.	
26. Floor of Engine-room . .	Italian mosaic.
Walls of Engine-room . .	White glazed bricks.
27. Staircases	
28. Electric Lift	
29. **Delivery of Coal** to Power-house, one end	By rail to private siding, dumped by a hydraulic ram into the crusher pit. Through a crusher and screen operated by a motor, 10 H.P. enclosed shunt motor, 650 R.p.m.

[*Continued on p.* 496.

1.	**Motherwell.**	**Thornhill.**
2.	Motherwell is a duplicate of Yoker, except condensing plant.	£45, including 6000 K.W. Transmission for 10,000 K.W. See details in Chap. I. p. 8.
3.	Clyde Valley.	Yorkshire Power Co.
4.		Dewsbury, between River Calder and railway siding.
5.		
6.		Fig. 342, p. 466.
7.	3 phase, 25 cycles, 11,000 volts.	10,000 volts, 50 cycles, 3 phases; 2000 volts, 50 cycles, 3 phases; 500 volts continuous current; 400 volts, 50 cycles, 3 phases; 230 volts, 50 cycles, 3 phases.
8.	From 10 substations.	Collieries, etc.
9.		Fig. 348, p. 469.
10.		3ft. bed of concrete over whole area.
11.		Steel frame, brick panelled.
12.		Redpath, Brown & Co.
13.		
14.		
15.		Fig. 364, p. 485.
16.		
17.	186ft. by 50ft.	70ft. by 80ft.
18.	252ft. by 43ft.	100ft. by 50ft.
19.		
20.		
21.		Fig. 365, p. 484.
22.		
23.		
24.		
25.		
26.		
27.		
28.		
29.		By road, rail, or river. Into hoppers beneath road and rails.

[*Continued on p.* 497.

1. **Name of Generating Station** .	**Radcliffe.**
2. Cost per *ultimate* rated K.W. capacity	
3. Owners	Lancashire Electric Power Co.
4. Location	Radcliffe, between the River Irwell and the Lancashire & Yorkshire Ry.
5. Area	20 acres area is secured.
6. Frontage	
7. Supply to Consumers . .	10,000 volts, 3 phase current, an area covering 1200 square miles.
8. Consumers	
9. Buildings	Fig. 354, p. 474.
10. Foundations	
Piers	
11. Type of Structure . . .	
12. Maker of Frame . . .	
13. Erection by	
14. Wharf Wall	
Length and Height . .	
15. Plan of Buildings . . .	
16. Dimensions	
17. Boiler-house	
18. Engine-room	
19. Transformer H. . . .	
20. Height	
21. Sectional Elevation of Buildings	
22. Roof-glazing	
23. Basement Floor . . .	
24. Floors of Boiler-room . .	
Walls of Boiler-room . .	
25. Floor of Switchboard Galleries .	
26. Floor of Engine-room . .	
Walls of Engine-room . .	
27. Staircases	
28. Electric Lift	None.
29. Delivery of Coal to Power-house, one end	By railway, a single line near the station buildings, containing hoppers. Each truck is hauled and tipped by electric loco-crane into one of the hoppers (only one at present). Stothert & Pitt, two G. E. 58 B.T.H. motors for hauling and one 30 H.P. motor for hoisting or tipping, overhead trolley 220 volts.

[*Continued on p.* 498.

1.	Brimsdown.	Power Station of the English M'Kenna Process Co., Ltd.
2.		
3.	North Metropolitan Electric Power Co.	English M'Kenna Process Co., Ltd.
4.	On Lea Canal near Ponders End Station, G. E. Ry.	Dock Road, Birkenhead, Liverpool.
5.		
6.		
7.	C. C. 240, 480, and 500 volts. A. C. to meet requirements.	
8.	Lighting and Tramways.	
9.	Fig. 349, p. 469.	
10.	Concrete on gravel.	
11.	Steel.	Steel frame and 14-inch brick between stanchions in engine-room.
12.	Dorman & Long.	
13.	Ditto and Clift Ford, Willesden.	Galvanised sheeting in boiler-house.
14.	A. Pedrette & Co.	
15.	C. W. Gray, 11 Adam Street, W.C. Fig. 366, p. 486.	Fig. 368, p. 489.
16.	165ft. × 152ft.	78 × 50 × 25 ft. mean height.
17.	Single-span Roof.	9 × 50 × 44 ft. mean height.
18.		
19.		
20.	41ft. to apex of roof.	
21.	Fig. 367, p. 487.	
22.	S. Deards.	Figs. 369, 370, pp. 488, 490.
23.		
24.	Concrete.	
25.	Concrete.	
26.	Tiled.	Faced white glazed bricks 8 ft. up.
27.	w. i.	
28.	None.	
29.	Canal. Figs. 376–378, p. 511.	By road or rail.

[*Continued on p.* 499.

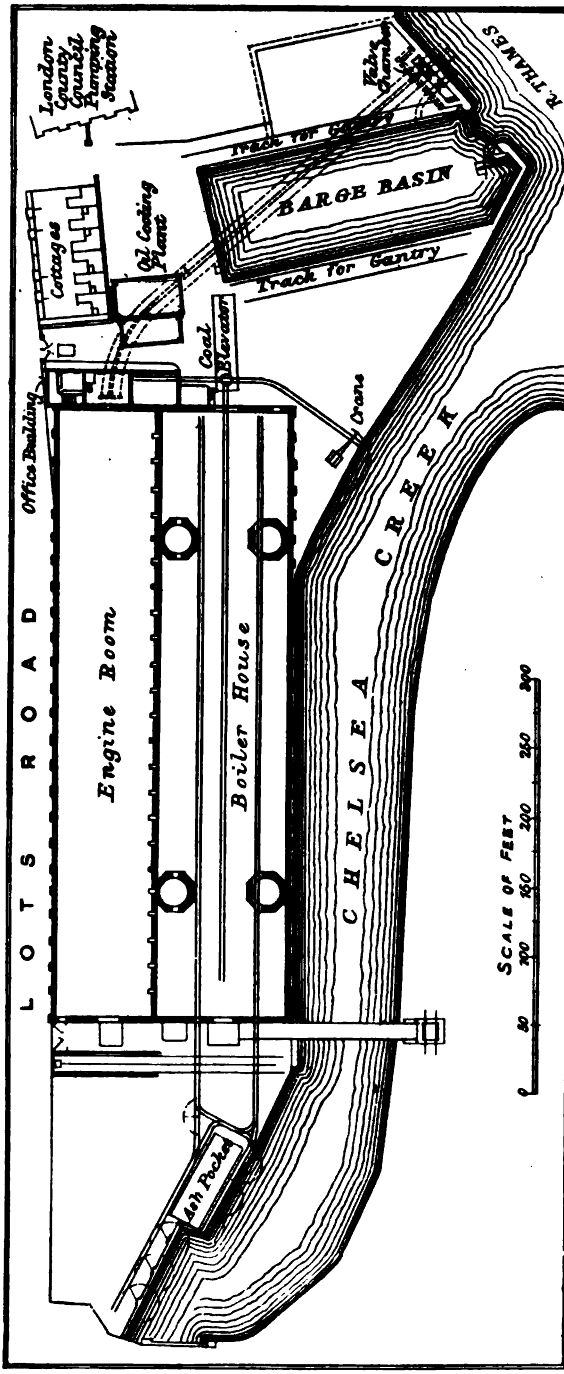


FIG. 388.—Site: Lots Road, Chelsea.

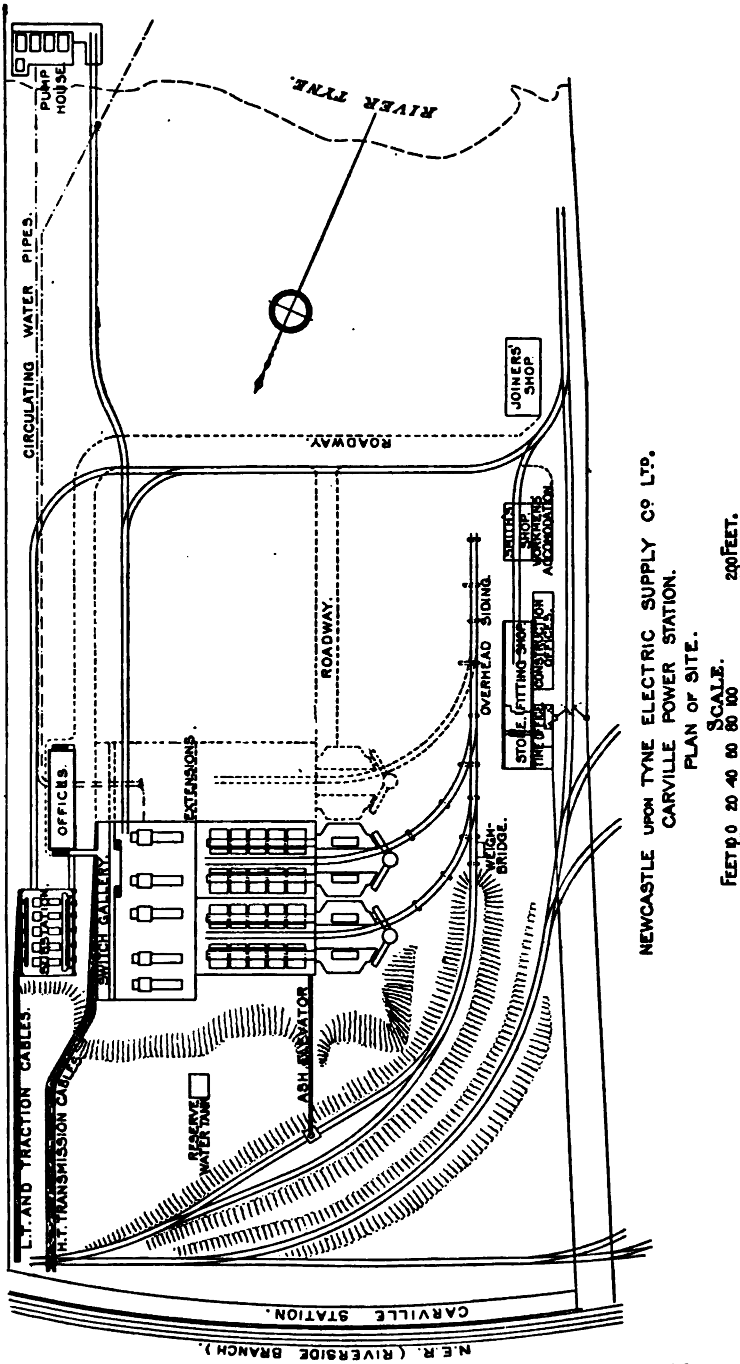


FIG. 339.—Site: Carville. (*Inst. Elec. Engrs.*)

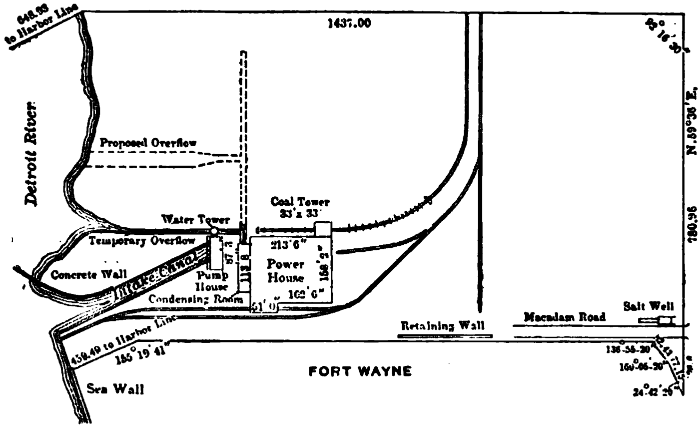


FIG. 340.—Site: Delray, Detroit.
(*Elec. World and Engr.*)

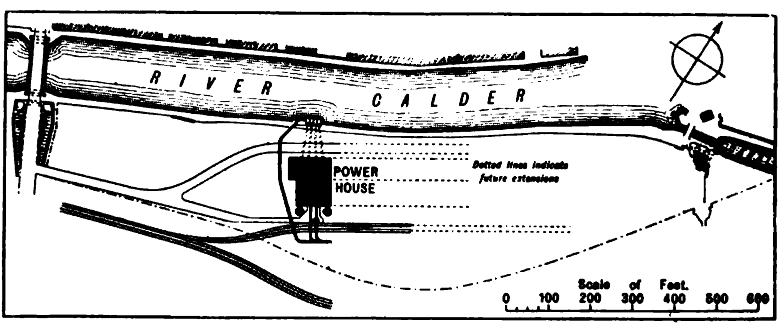


FIG. 342.—Site: Thornhill P.H.—Yorkshire Power Co.

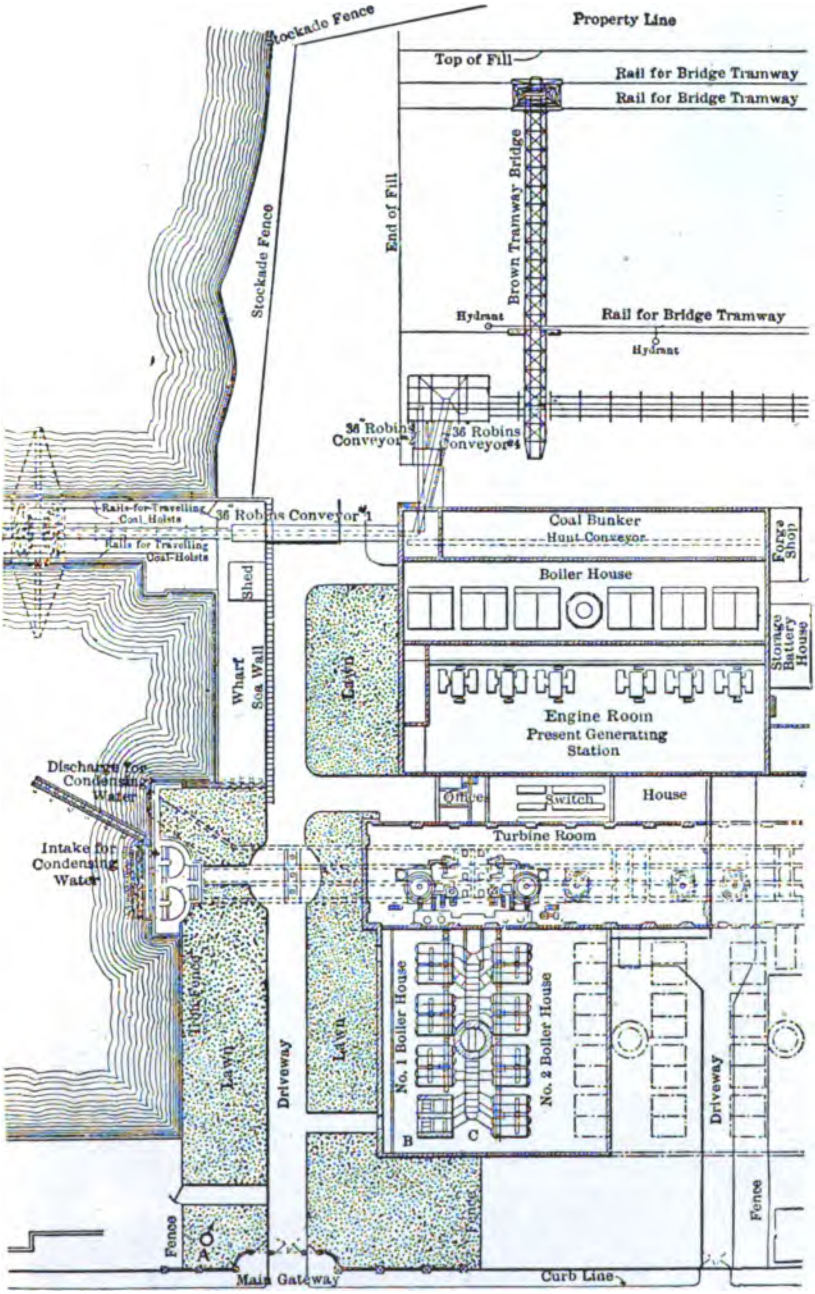


Fig. 341.—Site: Boston-Edison Power-Houses and Coal Storage.

"Present" Generating Station: 6 × 1500 K.W. Vertical Compound Piston Engines.
Turbine Room: 2 × 5000 K.W. Curtis Sets (220 Ft., built for 4).
Room for Extension to 650 Ft. × 48 Ft. to take 12 such Sets.

(From *Power.*)

FIG. 343.

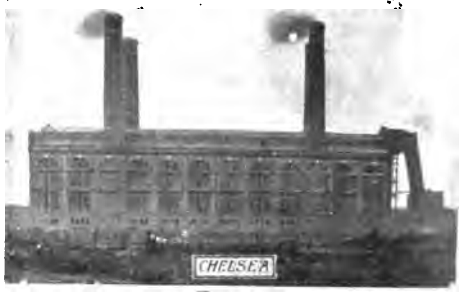


FIG. 344.

FIGS. 343 and 344.—Lots Road, Chelsea. (*Two Views by B. Westinghouse Co.*)

FIG. 345.

FIG. 347.

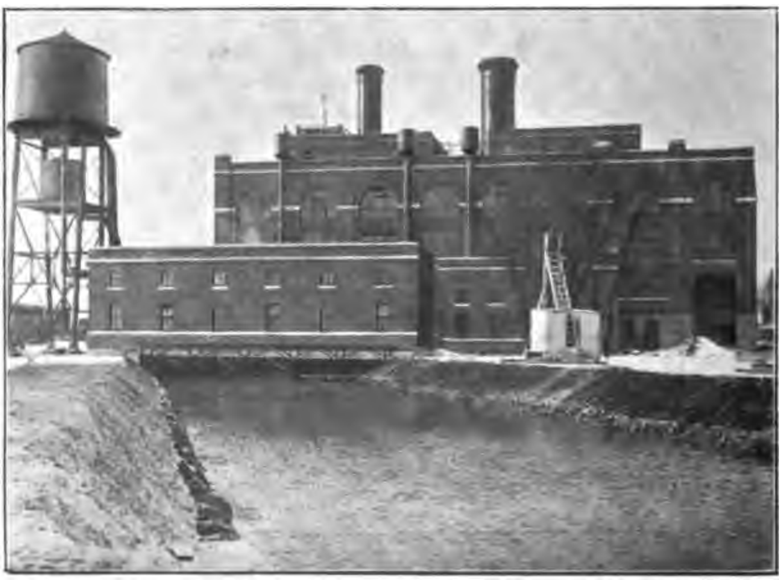


FIG. 346.—Delray, Detroit Edison Co. (From *G. E. Co. of New York.*)

FIG. 348.—Thornhill, Yorkshire Power Co. (*Electrical Review.*)

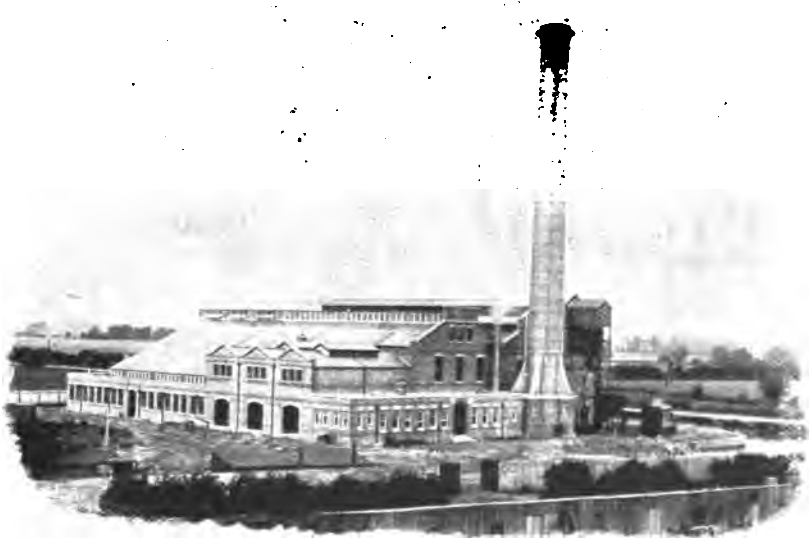


FIG. 349.—Brimsdown: North Metropolitan E.P.S. Co. (*Babcock & Wilcox.*)

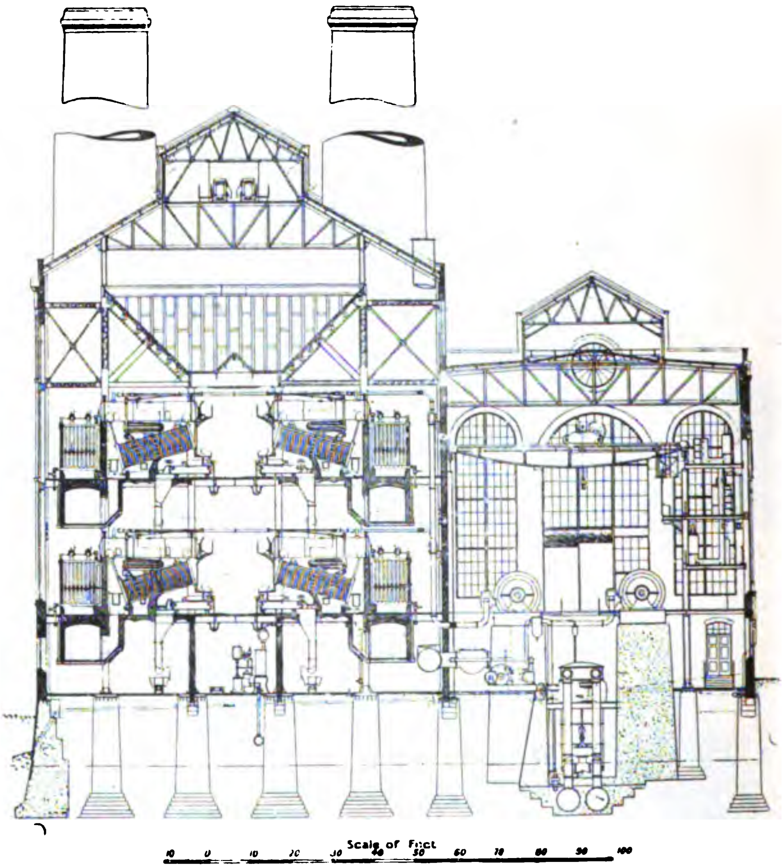


FIG 350.—Lots Road, Chelsea: Sectional Elevation.

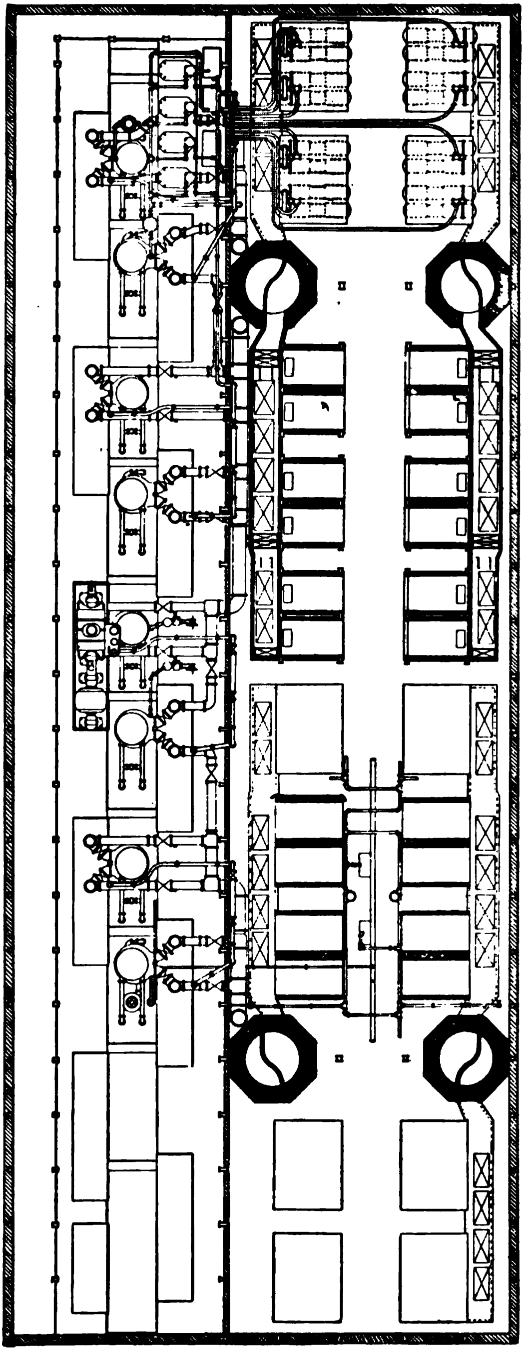


FIG. 351.—Lots Road, Chelsea: Plan of Buildings.
(*Tramway and Railway World.*)

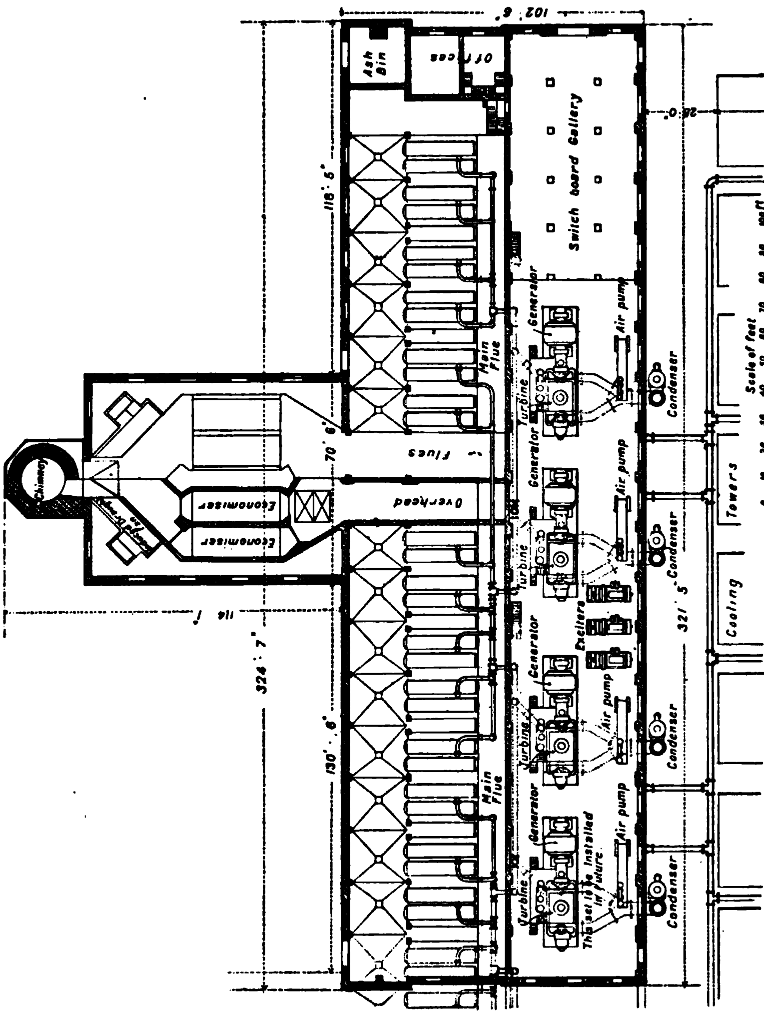
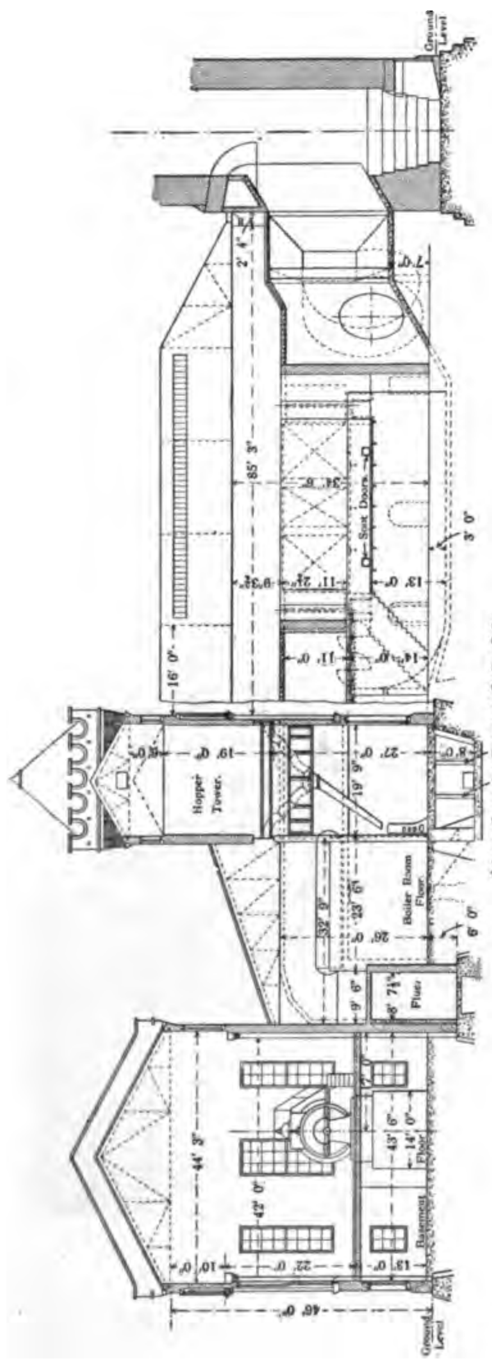


FIG. 352.—Neasden : Plan and Elevation of Power-House. (*Tramway and Railway World.*)



FIGS. 353.—Neasden: Plan and Elevation of Power-House.
(*Tramway and Railway World.*)

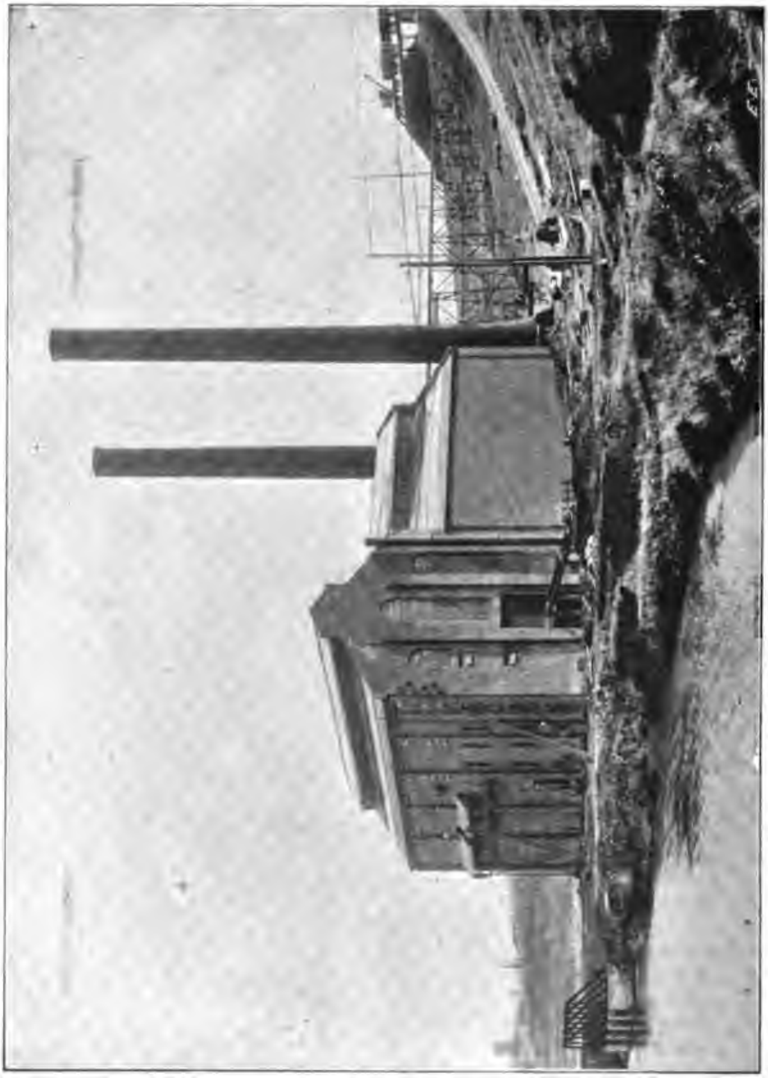


FIG. 354.—Radcliffe, Lancashire Power Co. (*Electrical Engineer.*)

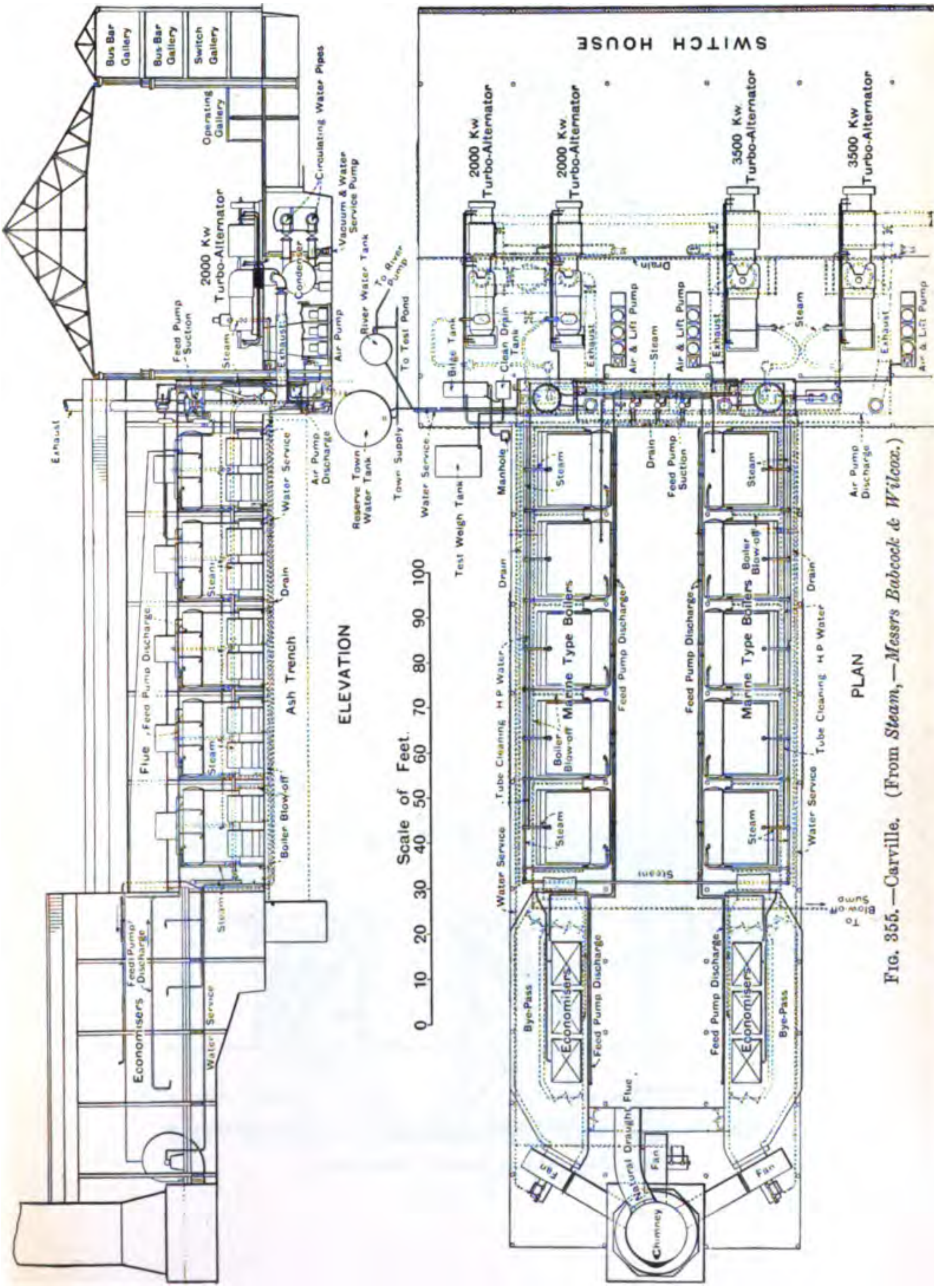


FIG. 355.—Carville. (From *Steam*,—*Messrs Babcock & Wilcox.*)

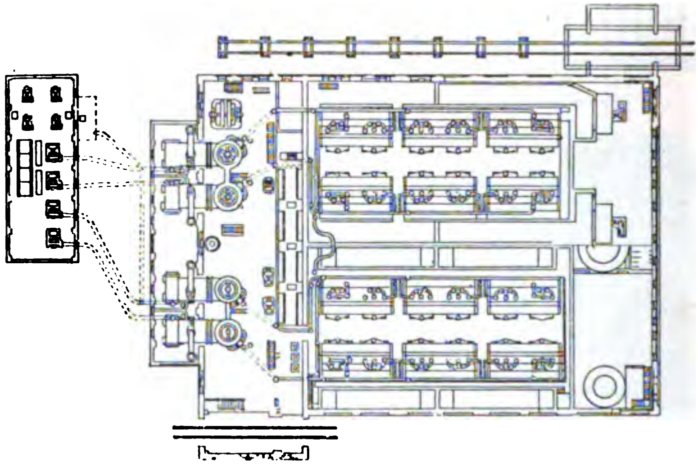


FIG. 356.—Delray, Detroit: Plan of Power-House.
(*Elec. World and Engr.*)

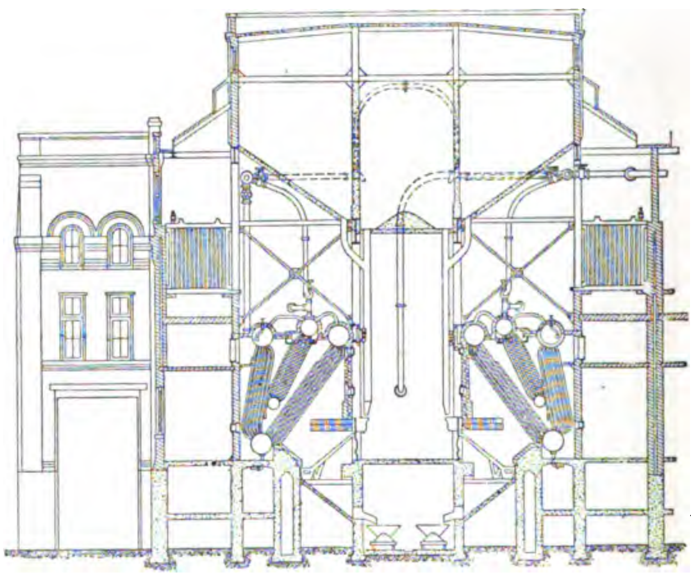


FIG. 358.—Delray, Detroit: Boiler-House.

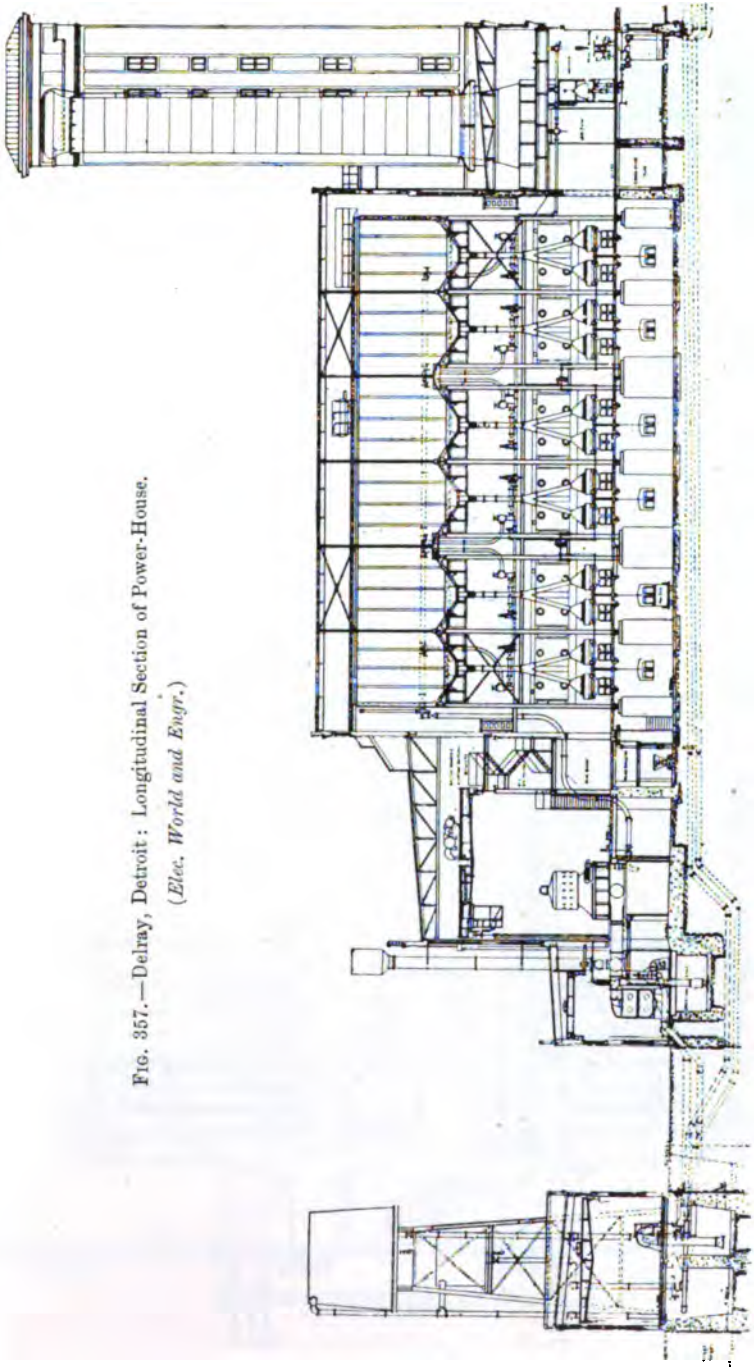


Fig. 357.—Delray, Detroit: Longitudinal Section of Power-House.
(*Elec. World and Engr.*)

No. 2 (Turbine) Boiler-House. **No. 1 (Turbine) Boiler-House.**

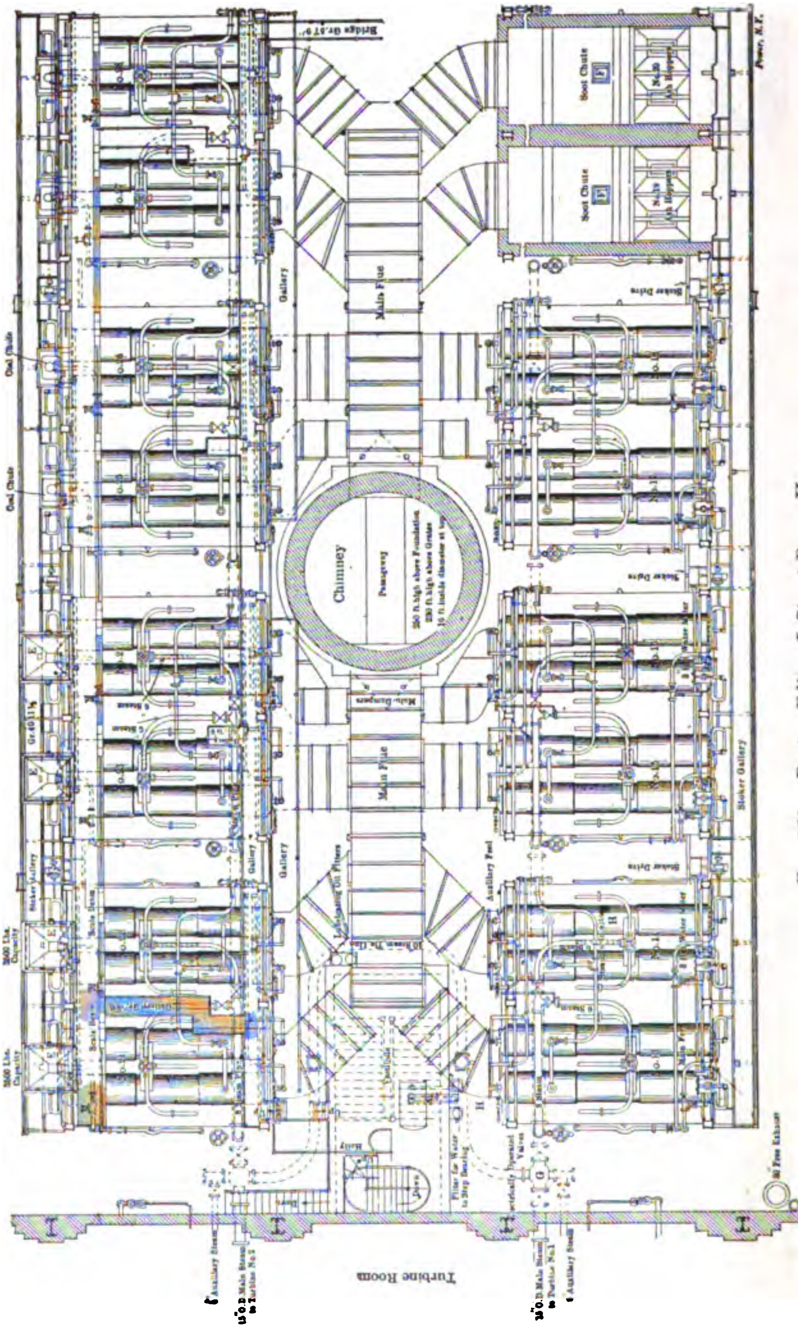


FIG. 359.—Boston Edison L Street Power-House.

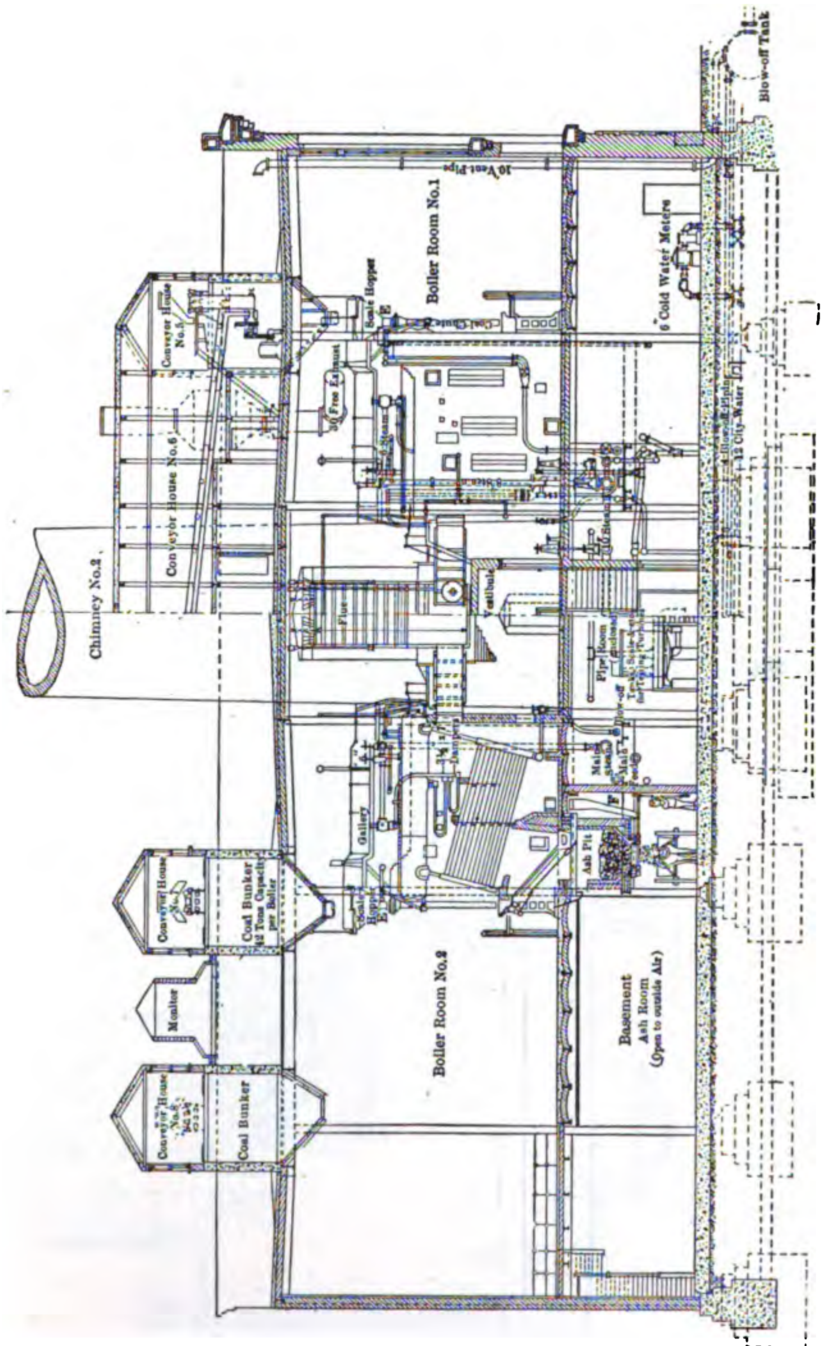


FIG. 360.—Boston Edison: Transverse Elevation of Boiler-House.

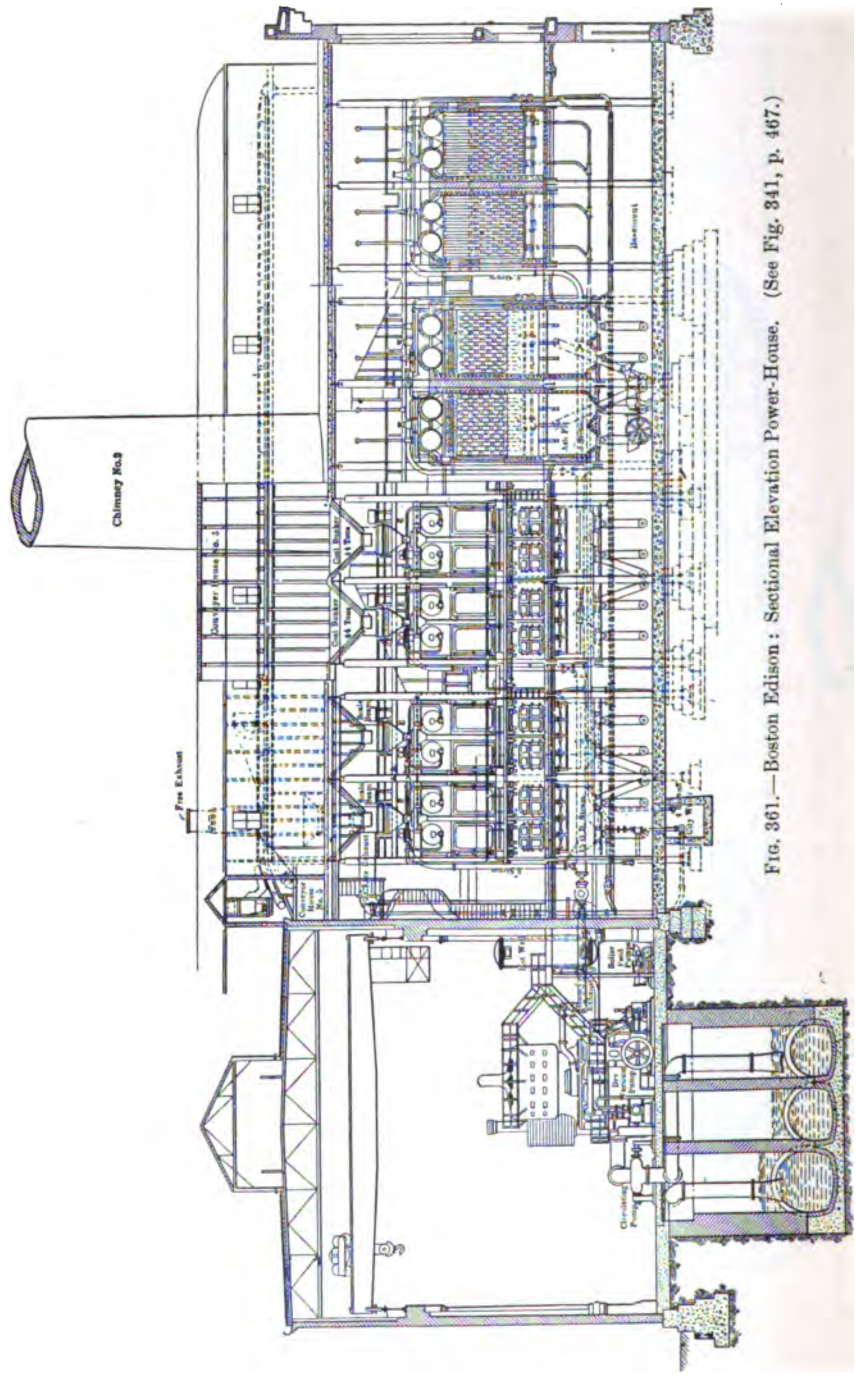


FIG. 361.—Boston Edison: Sectional Elevation Power-House. (See Fig. 341, p. 467.)

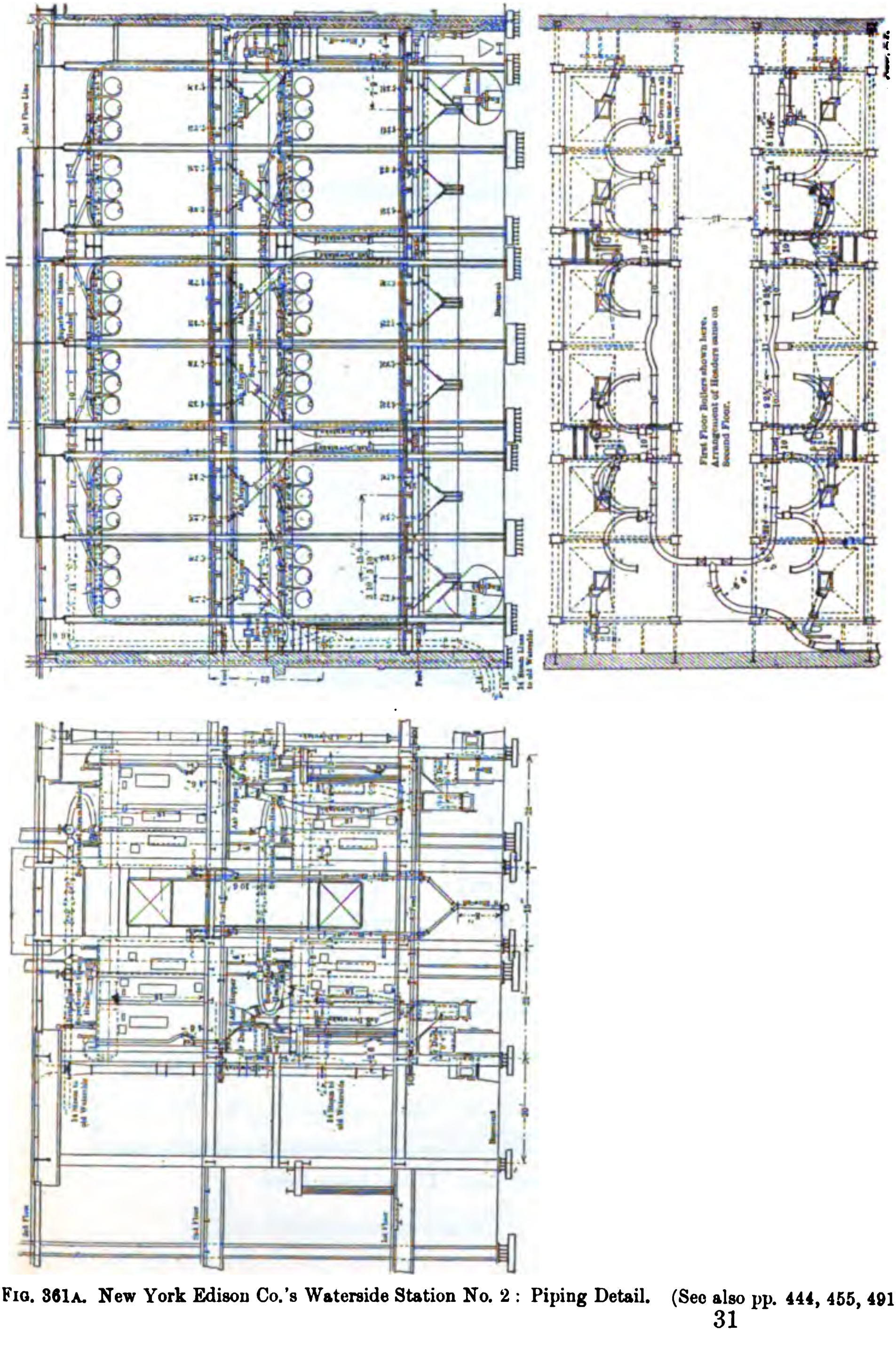


FIG. 361A. New York Edison Co.'s Waterside Station No. 2: Piping Detail. (See also pp. 444, 455, 491.)

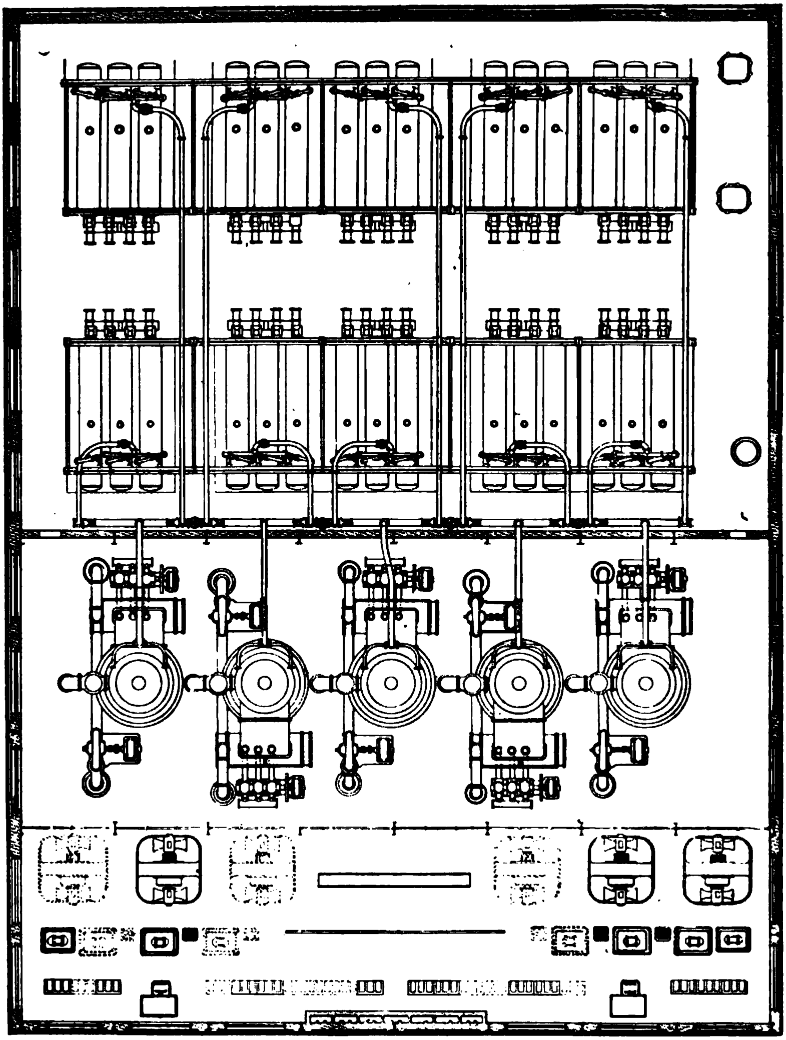


Fig. 362.—Quincy Point: Plan of Power-House.

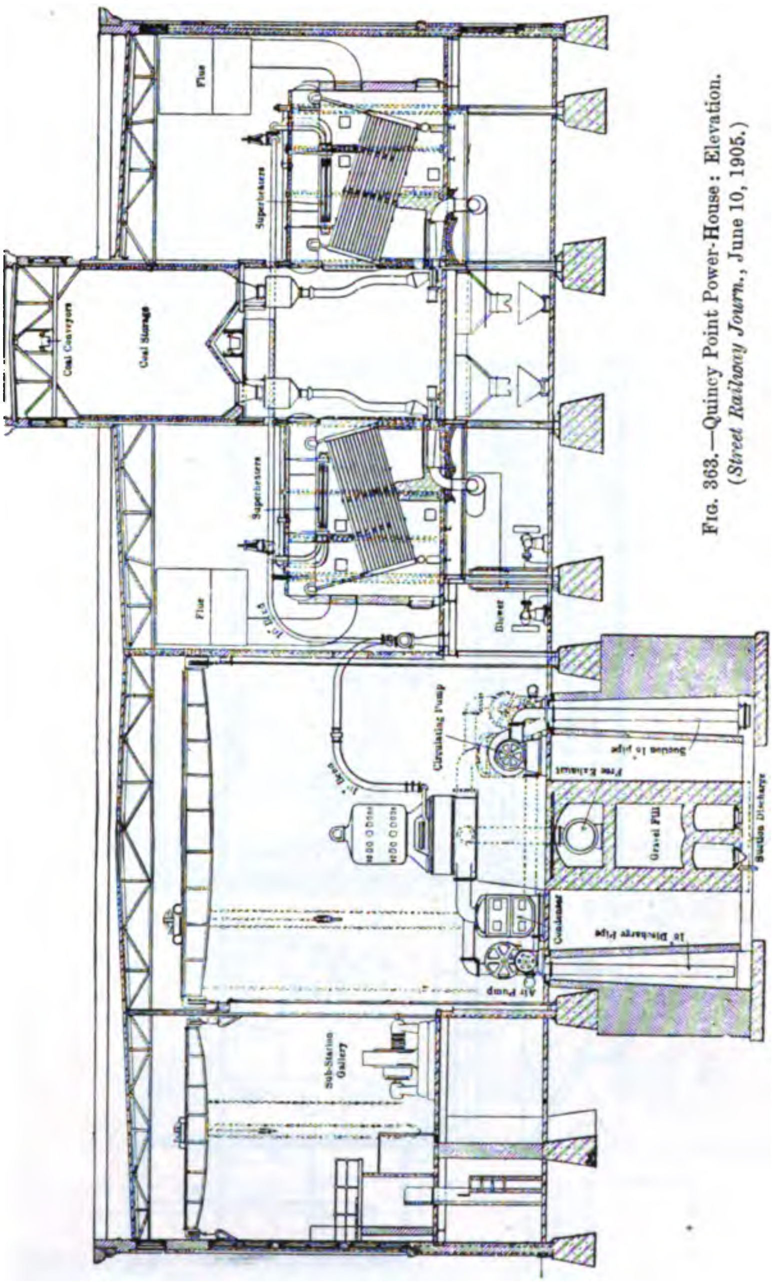


FIG. 363.—Quincy Point Power-House: Elevation.
(*Street Railway Journ.*, June 10, 1905.)

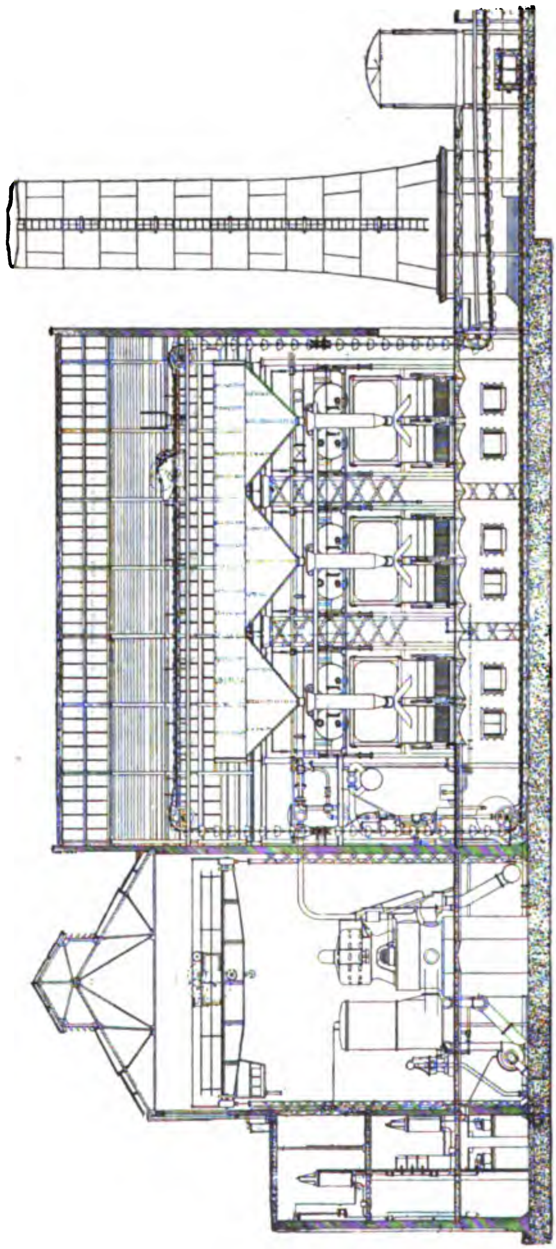


Fig. 364.

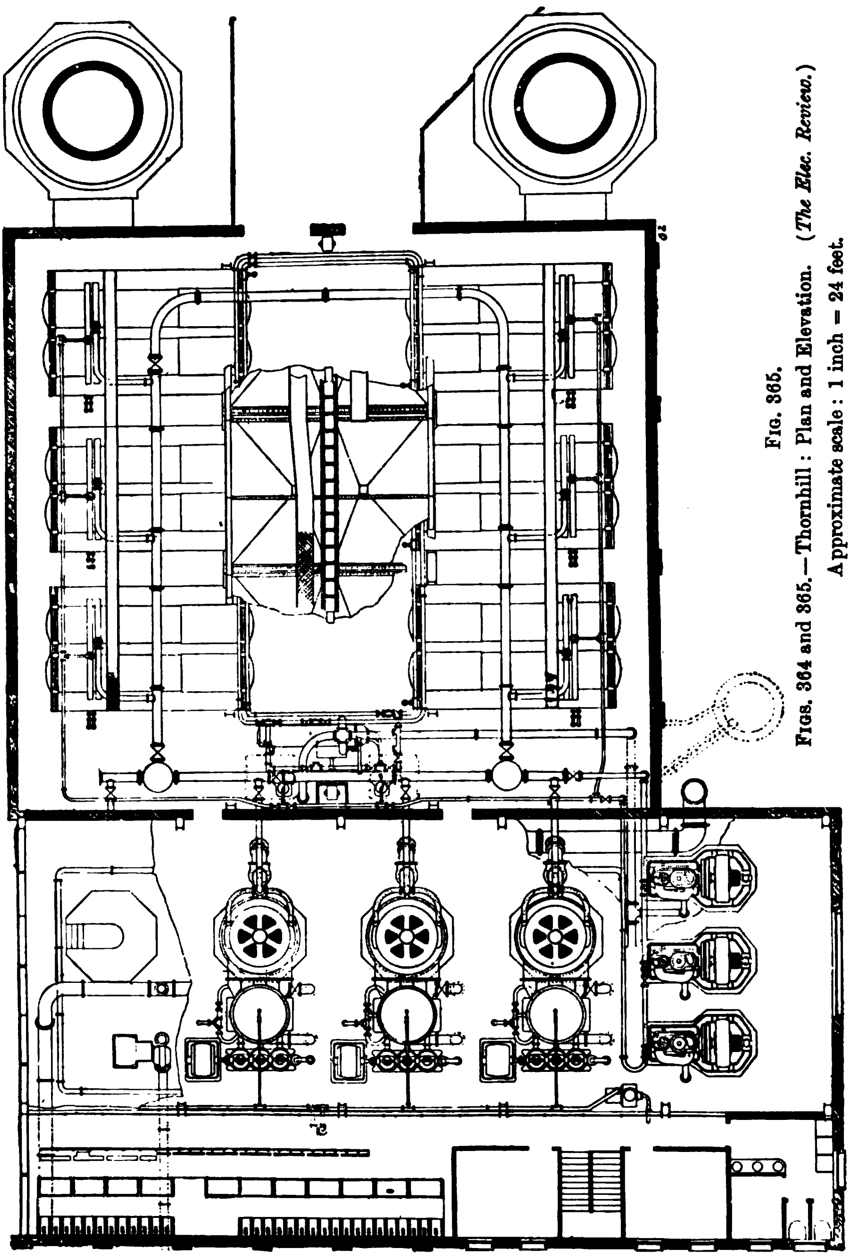


FIG. 365.

FIGS. 364 and 365.—Thornhill: Plan and Elevation. (*The Elec. Review.*)

Approximate scale: 1 inch = 24 feet.

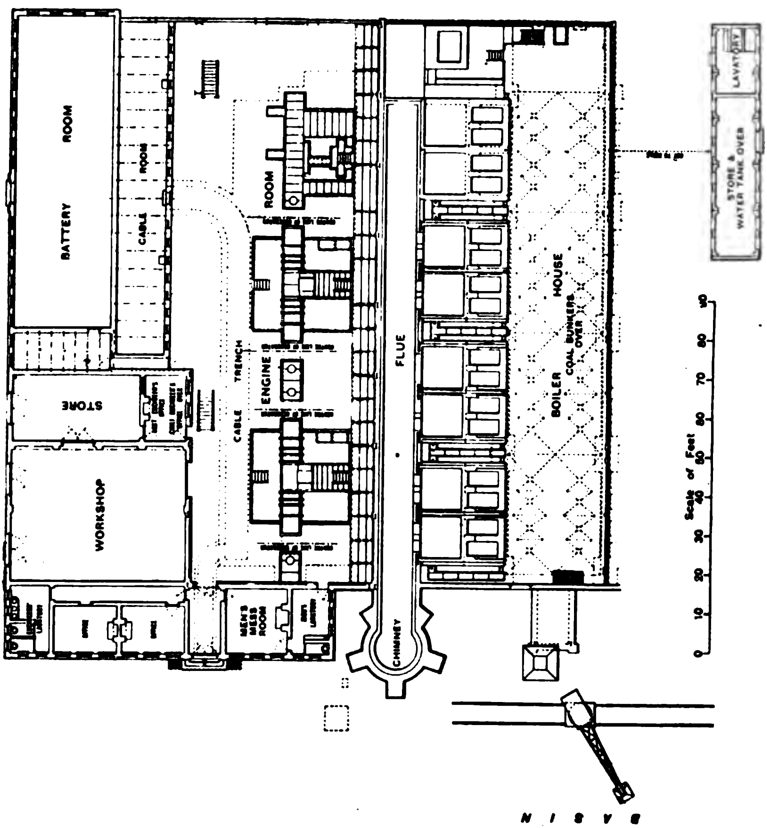

BATTERY ROOM
CABLE ROOM
STORE
WORKSHOP
MEN'S MESS ROOM
ENGINE ROOM
CABLE TRENCH
FLUE
CHIMNEY
BOILER HOUSE
COAL BUNKERS OVER
STORE & WATER TANK OVER
LAVATORY
Scale of Feet
0
10
20
30
40
50
60
70
80
90
BASIN

FIG. 366.

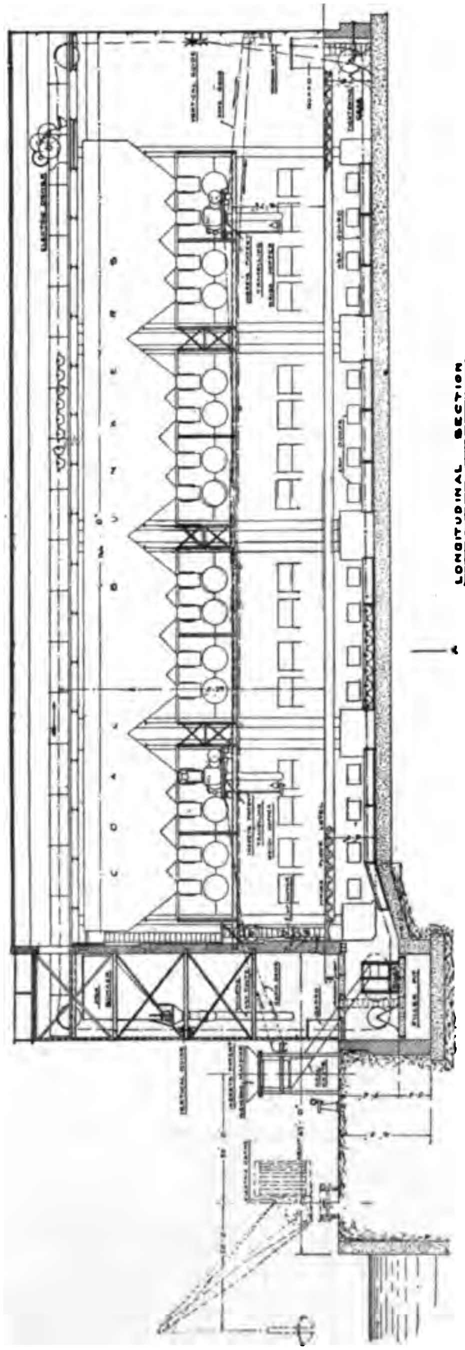


FIG. 367.

FIGS. 366 and 367.—Brimsdown: Plan and Elevation to different scales.
(*Steam,—Babcock & Wilcox.*)

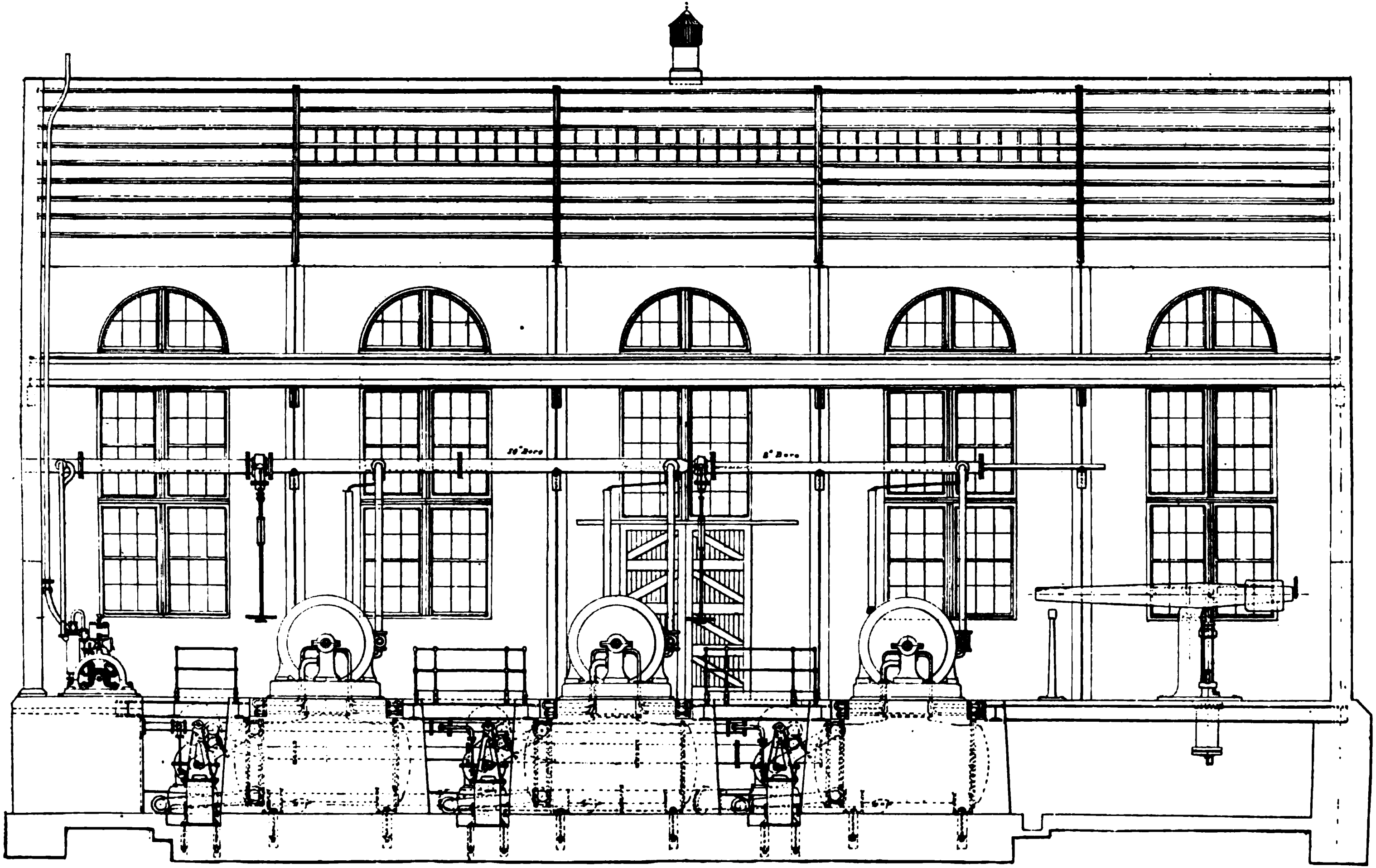


FIG. 369.

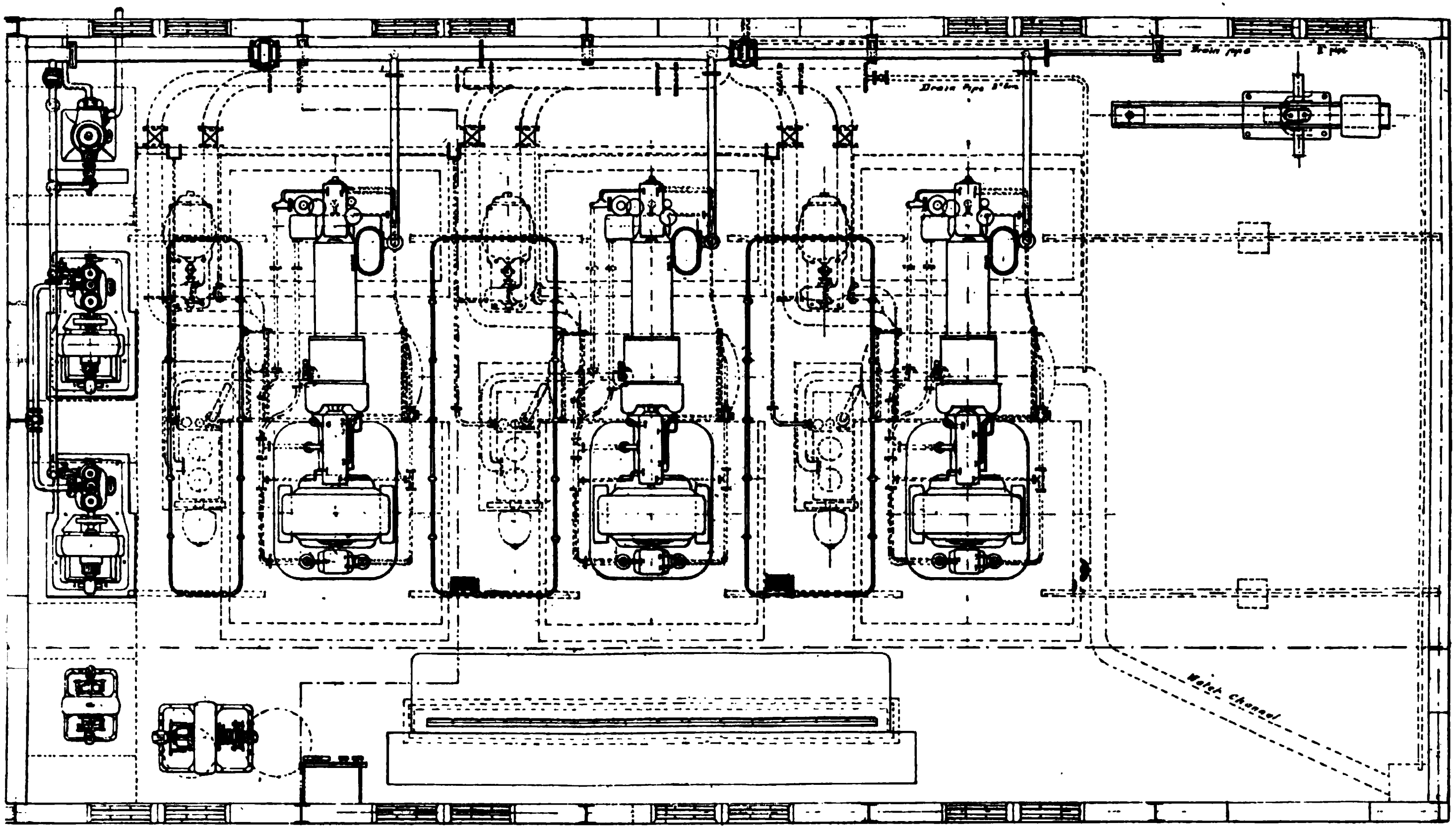


Fig. 368.

Figs. 368 and 369.—English M'Kenna Process Co.'s Power-House: Plan and Elevation. Scale, 1 : 144.

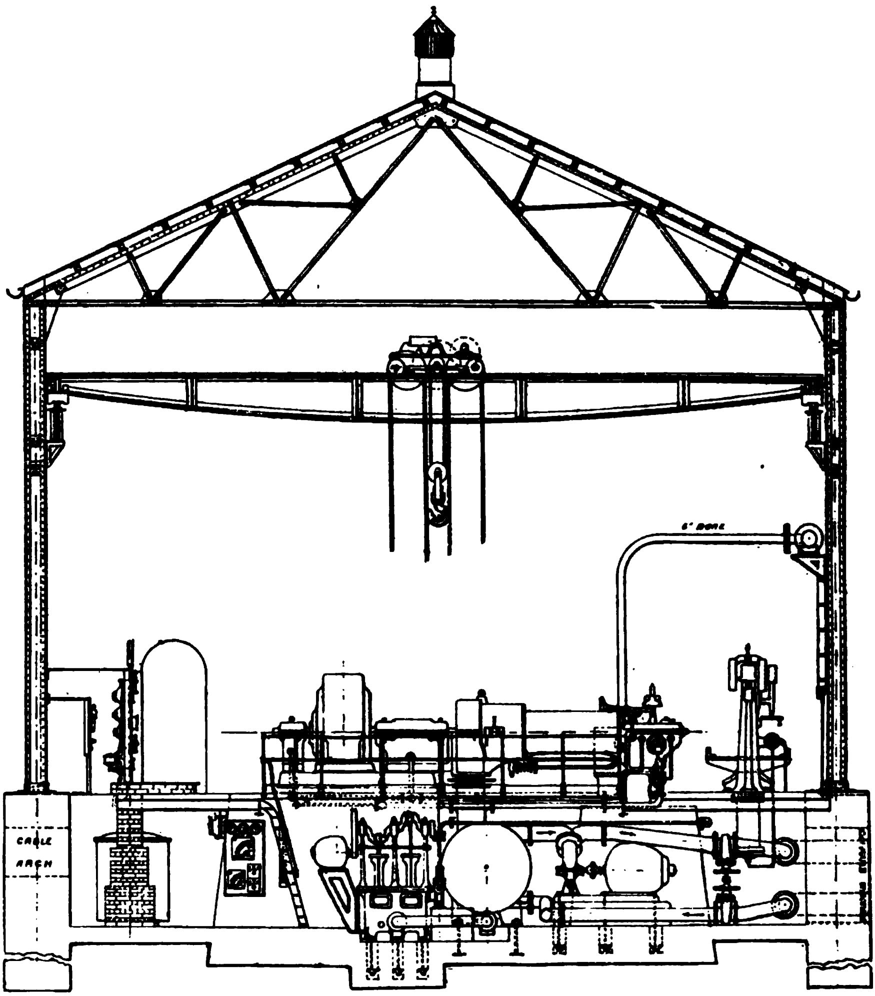


FIG. 370.—English M'Kenna Co. Scale, $\frac{1}{144}$ full size.

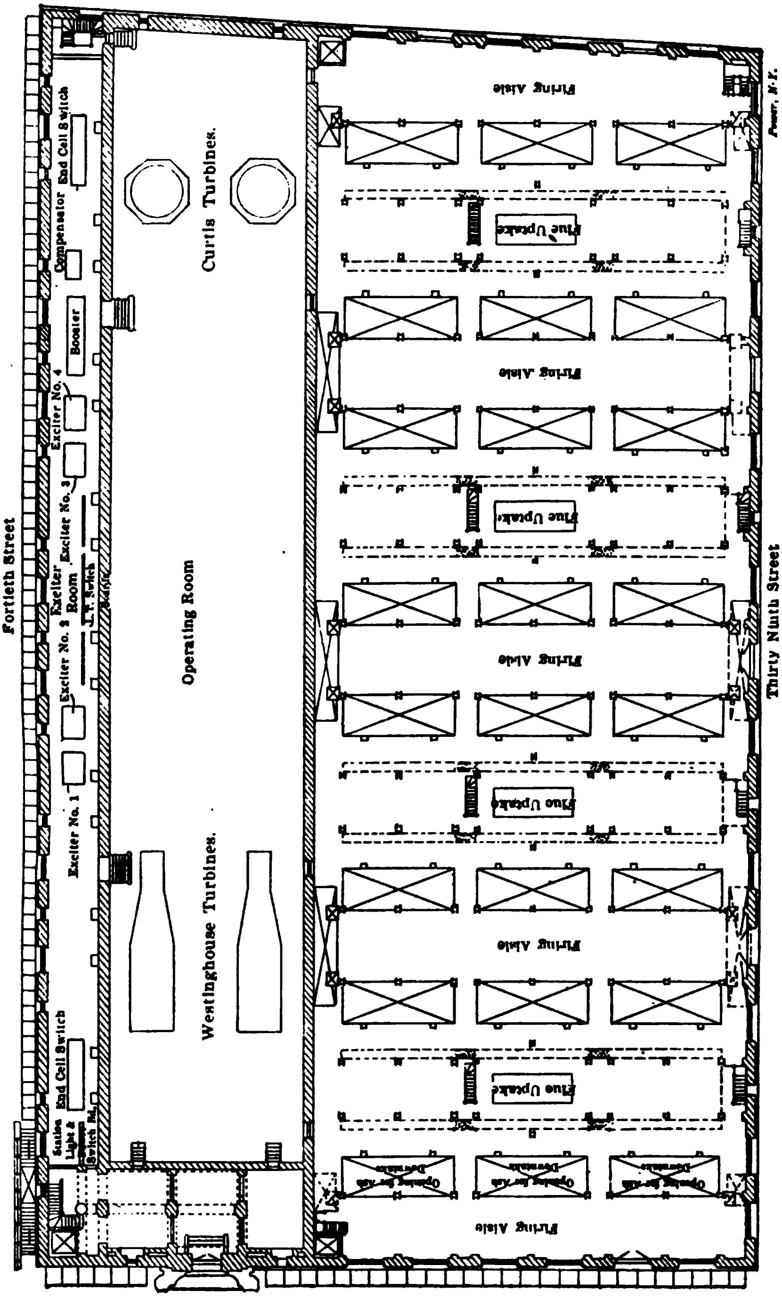


FIG. 870A.—New York Edison Co.'s Waterside No. 2 Station: First Floor Plan. (See also pp. 444, 455, 481.)

Name of Generating Station	Lots Road, Chelsea. [*From p.* 456.
30. Conveyors	See Figs. 371, 372, 373, p. 508.
Conveyor capacity	*At East End* of power-house by water.
,, driven by	A tidal basin spanned by cranes.
Speed of travel	
Direction of travel	
Motor driving Conveyor	
31. **Wharf Cranes**: Number	2
Capacity	1½ tons grab on each.
Maker	Beecham & Keetman, Duisburg.
Driven by	Electric Motors Horse-power volts.
Supplied by	Conductors in slotted conduit.
32. **Coal Weighed**	Automatically in tower, thence through hoppers to
33. Rubber Belt Conveyor	At ground level. Belt 380ft. by 30in. by ½in.
Driven by	15 horse-power, 220 volt, 3 phase motor.
Belt delivers to	2 Crushers.
34. Conveyors outside Power-house	Inclined. Fig. 373, p. 508.
Capacity	240 tons per hour.
Lift	145½ft.
Number of Buckets	154, spaced 2ft. 8ins. apart.
Driven by	30 horse-power 3 phase motors at top of each.
Maker of Conveyor	John A. Mead & Co., New York.
Steel inclined Tower	Mayoh & Haley.
35. **Conveyors** above bunkers	2 Rubber belts 970ft. and 980ft. by 2ft. by $\frac{7}{16}$in.
Capacity	
Driven by	20 horse-power motors, 220 volts, 3 phase, each belt. On same guides Narrow Gauge Railway Track for Coal-tipping device.
Maker of Conveyors	Mead, Morrison & Co., New York.
36. **Bunkers**: Capacity	15,000 tons (3 weeks' supply); 0·26 ton per ultimate K.W. capacity.
37. Daily Consumption	800 tons.
38. Coal fed to Boiler	By gravity through chutes.

[*Continued on p.* 500.

[*From p.* 457.

	Neasden.	**Carville.**
30.		Waggons, before passing to the bunkers, have to pass over a weigh bridge, operated electrically. Motor operated forward raises waggon on flanges of its wheels, scotches waggon, sets signal points, records weight. Switch reversed, it lowers waggon, clears signal and wheels.
31.		
32.	Automatically by Avery machines, fitted into shoots between bunkers and stoker hoppers.	Automatic weighing machine to stoker hoppers.
33.		
34.	3 phase motors, 440 volts. Graham, Morton & Co., Ltd.	
35.	Continuous bucket type.	
36.	1500 tons.	1200 tons. Dimensions of bunker is 95ft. length, 22ft. wide, 14ft. deep; steel plate divided in 5 compartments.
37.		
38.	Through hoppers, by gravity.	From bunkers, through cast-steel mouth-pieces.

[*Continued on p.* 501.

Name of Generating Station	**Delray, U.S.A.** [*From p.* 458.
30. Conveyors	
Conveyor capacity	
,, driven by	
Speed of travel	
Direction of travel	
Motor driving Conveyor	
31. **Wharf Cranes**: Number	
Capacity	
Maker	
Driven by	
Supplied by	
32. **Coal Weighed**:	
33. Rubber Belt Conveyor	At ground level.
Driven by	
Belt delivers to	
34. Conveyors outside Power-house	
Capacity	
Lift	
Number of Buckets	
Driven by	
Maker of Conveyor	
Steel inclined Tower	
35. **Conveyors** above bunkers	From coal towers to bunkers.
Capacity	70 tons per hour.
Driven by	
Maker of Conveyors	
36. **Bunkers**: Capacity	80,000 tons.
37. Daily Consumption	215 to 300 tons.
38. Coal fed to Boiler	By gravity.

[*Continued on p.* 502.

	L. Street Station, Boston, U.S.A.	**Quincy Point, Mass., U.S.A.** [*From p.* 459.
30.	2 coal towers; 1 and $1\frac{1}{2}$ tons coal tower buckets deliver into a 36in. Robins belt conveyor in three sections. convey coal to a Brown bridge, 60ft. above coal yard; 155ft. span. 82ft. cantilever. The hoist on the bridge has a 2-ton bucket, capable of making one trip per minute. The coal can be taken up from any part of yard by 20-in. Robins belt conveyor. In case of spontaneous ignition, numerous hydrants are available, but coal can be frequently turned over by means of bridge to avoid this.	Deliver to crusher hoppers, through a concrete tunnel that extends from the wharf to a point under the boiler-room.
31.	70,000 tons total coal yard capacity. 20,000 tons total coal yard capacity under trestle. For turbine plant, conveyor housed above delivers to 44-ton bunker over each boiler. (2000 lb. ton.)	
32.	Hand operated valves to weighing hopper of 3600 lbs. capacity. See Fig. 360 and 361, p. 479.	
33.		
34.		
35.		Bucket conveyor through tunnel and up to bins above boilers. Variable speed 350 volt a.c. motors. M'Caslin type, by T. A. Mead & Co.
36.	40 tons (2240 lbs.) each boiler hopper, 40 hours' consumption at 20 lbs. per sq. ft. of grate).	
37.		
38.		Through chutes.

[*Continued on p.* 503.

Name of Generating Station .	Yoker. [From p. 460.
30. Conveyors	
Conveyor capacity . .	
,, driven by . .	
Speed of travel . . .	
Direction of travel . .	
Motor driving Conveyor .	
31. **Wharf Cranes**: Number . .	
Capacity	
Maker	
Driven by	
Supplied by . . .	
32. **Coal Weighed** . . .	Automatically, each hundredweight recorded on indicator.
33. Rubber Belt Conveyor . .	
Driven by	
Belt delivers to . . .	
34. Conveyors outside Power-house	
Capacity	
Lift	
Number of Buckets . .	
Driven by	
Maker of Conveyor . .	
Steel inclined Tower . .	
35. **Conveyors** above bunkers .	Bucket Conveyor to bunker above boilers, Graham, Morton & Co.
Capacity	
Driven by	15 horse-power enclosed shunt motor.
Maker of Conveyors . .	
36. **Bunkers**: Capacity . .	
37. Daily Consumption . . .	
38. Coal fed to Boiler . . .	Through chutes with motor-driven agitator to prevent coal sticking.

[Continued on p. 504.

Motherwell.	**Thornhill.** [*From p.* 461.
30.	
31.	
32.	By automatic measuring chutes.
33.	
34.	
35.	Buckets 1 cu. ft. each convey 25 tons per hour. 45ft. per minute in either direction, 10 horse-power, 750 revolutions per minute, 220 volt motor, Babcock & Wilcox.
36.	
37.	
38.	By gravity through chutes.

[*Continued on p.* 505.

Name of Generating Station	Radcliffe. [*From p. 462.*
30. Conveyors	See Fig. 375 at highest level, also item 32 below, p. 511.
Conveyor capacity	
,, driven by	
Speed of travel	
Direction of travel	
Motor driving Conveyor	
31. **Wharf Cranes**: Number	Electric locomotive crane.
Capacity	
Maker	
Driven by	
Supplied by	
32. **Coal Weighed**	The coal is discharged from the hopper into a trolley car of about 20cwt. capacity, is then weighed, and the weight automatically recorded. The loaded car travels down 3 per cent. gradient. The car, after attaining momentum, picks up an endless rope which lifts a counterweight. The car unloads itself over any bunker, and is then drawn back by the counterweight and projected to the top under the discharging hopper. See Fig. 375, p. 511.
33. Rubber Belt Conveyor	
Driven by	
Belt delivers to	
34. Conveyors outside Power-house	
Capacity	
Lift	
Number of Buckets	
Driven by	
Maker of Conveyor	
Steel inclined Tower	
35. **Conveyors** above bunkers	
Capacity	
Driven by	
Maker of Conveyors	
36. **Bunkers**: Capacity	
37. Daily Consumption	
38. Coal fed to Boiler	

[*Continued on p.* 506.

Brimsdown. [*From p.* 463.

30.

31. One.
1 ton grab.

Smith & Sons, Rodley.
C. C. motors, Siemens.

32. Grab discharges into Klein weighing hopper. See Fig. 378.

33. It is weighed again before delivery to stoker hoppers. See Fig. 379, p. 512.

34. Vertical. Fig. 376. This runs over bunkers also.

40 tons per hour.
174. Fig. 377, p. 511.
6 Horse-power motor.
Babcock & Wilcox.

35. Same as item 34, *q.v.*

36. 800 tons.

37. 30–33 tons: 1/11/1905.

38. Through travelling Klein Ingray Weigher. Fig. 379, p. 513.

Power Station of the English M'Kenna Process Co., Ltd.

[*Continued on p.* 507.

Name of Generating Station	Chelsea. [From p. 492.
39. **Ash Removal**	Ash chutes to basement.
Special Ash Railway	Self-dumping buckets on Narrow Gauge Railway.
Haulage in Basement	Accumulator Locomotive by B.T.H. Co. Ltd.
Emptied into Barges by	Pneumatic hoists on river wall.
Stored in	Ash pocket.
40. **Coal now used**	
Calorific Value	
Cost per ton	
41. **Boiler Flues**: Location	
Flue Area	
42. Chimneys: Builders	Alphons Custodis Chimney Construction Co.
Material	
Number	4.
Height	275ft. from basement floor.
Diameter at top	19ft.
Area at top	283 sq. ft.
,, bottom	
Height of Firebrick Lining	
Foundations Dimensions	42ft. by 42ft. by 34ft. 6in. below ground-floor level.
,, Volume	2200 cubic yards of concrete in each foundation.
43. **Boilers**: Location	On two floors.
Pressure	175 lbs. per sq. in.
Maker	Babcock & Wilcox, Ltd.
Number	64, with room for 16 more.
Piped in sets of	8 boilers for each turbine. Figs. 380, 381, p. 514.
Heating Surface each	5212 sq. ft.
Grate Area each	83 sq. ft.
Number of Tubes in Width and Height	
Capacity each per hour normal	17,000 lbs. per hour.
Feed water temperature	
Capacity when forced	

[Continued on p. 516.

[*From p.* 498.

	Neasden.	Carville.	
39.	By coal conveyor.		
40.		Northumberland small coal. 11,000 B.Th.U. 5s. 9d. per ton in 1904.	
41.	28ft. wide; height, 6ft. to 20ft. (overhead).	2 above boilers on steel girders.	
	104 sq. ft. main flue area.	Induced draught, with natural draught bye-pass.	
42.	British Westinghouse Co.		
	Brick.	Steel.	
	1.	1.	
	200ft.	60ft. above flue level.	
	15ft.	14ft.	
	176 sq. ft.	150 sq. ft.	
	100ft.		
	19 by 21 by 21ft.		
	310 cubic yds.		
43.	Floor on same level as basement floor.	Original.	*Extensions on order.*
	180 lbs. per sq. in. (?) 200.	200 lbs. per sq. in.	*200.*
	Babcock & Wilcox.	Babcock & Wilcox.	*Stirling.*
	10 marine type.	10.	*8.*
	3 with 10in. mains to headers.		
	5730 sq. ft.		*6380 sq. ft.*
	118 sq. ft.		*110 sq. ft.* *(5·17 lbs. per hour per sq. ft.)*
	20,000 lbs. water per hour normal.	20,000 lbs. of water	*33,000 lbs.*
	With feed 100° F.	With feed at 100° F.	*41,250 lbs.*
	28,000 lbs. of water per hour when forced.	28,000 lbs. of water	

[*Continued on p.* 517.

Name of Generating Station	Delray. [*From p.* 494.
39. Ash Removal	By brick-lined hoppers.
Special Ash Railway	Thence by gravity to trucks on narrow gauge railway in basement.
Haulage in Basement	At present by hand. An electric storage battery locomotive will be installed.
Emptied into Barges by	
Stored in	
40. Coal now used	
Calorific Value	
Cost per ton	
41. Boiler Flues: Location	
Flue Area	30 sq. ft. per 1000 boiler horse-power.
42. Chimneys: Builders	
Material	Steel, lined with red firebrick throughout.
Number	3.
Height	132ft.
Diameter at top	11ft. (first and second); 16ft. (third). These stacks provide a draught to operate the boilers about $\frac{3}{4}$ of their rated capacity with the economisers cut out.
Area at top	103 sq. ft. and 201 sq. ft. (third).
,, bottom	
Height of Firebrick Lining	
Foundations Dimensions	4 fans are erected for mechanical draught, each 15 feet diam. by 6ft. 6in. wide at the periphery directly beneath the chimneys, and driven by Chandler & Taylor automatic steam engines, using less than 1 per cent. of the boiler power they serve.
,, Volume	
43. Boilers: Location	
Pressure	200 lbs. per sq. in.
Maker	Stirling Co.
Number	24.
Piped in sets of	6 for each turbine.
Heating Surface each	4834 sq. ft.
Grate Area each	
Number of Tubes in Width and Height	
Capacity each	520 horse-power.

[*Continued on p.* 518.

L. Street, Boston.	**Quincy Point.** [*From p.* 495.
39. Ashes fall into suspended pit. Soot chute marked F behind fire bridge, p. 479.	The ashes drop from front of boilers direct into cars on a narrow gauge track in the subcellar.
Horse-drawn carts.	
40	George Creek, Cumberland Coal. 14,000 B.Th.U. per pound.
41.	
42.	
Custodis radial brick.	
	2.
250ft. above foundation; 232ft. above grate.	
16ft.	
200 sq. ft.; 425° to 525° F. temperature of gases.	
43.	Floor is 14ft. above grade; the subcellar is utilised for ash tracks.
175 lbs. per sq. in.	200 lbs. per sq. in.
Babcock & Wilcox.	8 by Aultman & Taylor, 2 by Babcock & Wilcox.
16.	Ten 750 horse-power water-tube boilers.
8.	2. Each pair of opposite boilers constitutes a boiler unit, and is provided with an engine-driven blower for forced draft.
5118 sq. ft.	
110 sq. ft. on incline, 1750 total.	
18 and 14, 18ft. long.	

[*Continued on p.* 519.

[From p 496.

Name of Generating Station	Yoker.
39. **Ash Removal**	By the coal conveyors.
Special Ash Railway	
Haulage in Basement	
Emptied into Barges by	
Stored in	
40. **Coal now used**	
Calorific Value	
Cost per ton	
41. **Boiler Flues**: Location	Along the back of the boiler-house.
Flue Area	
42. Chimneys: Builders	
Material	Custodis type of special perforated and moulded bricks.
Number	1.
Height	225ft. above foundations.
Diameter at top	11ft.
Area at top	103 sq. ft.
,, bottom	14ft. diam., 150 sq. ft.
Height of Firebrick Lining	85ft above foundations.
Foundations Dimensions	2116 sq. ft. area.
,, Volume	2 tons average weight over the entire area per sq. ft.
43. **Boilers**: Location	
Pressure	175 lbs. per sq. in.
Maker	Babcock & Wilcox.
Number	4 double-drum water tube.
Piped in sets of	
Heating Surface each	4400 sq. ft.
Grate Area each	
Number of Tubes in Width and Height	
Capacity	

[Continued on p. 520.

Motherwell.	**Thornhill.** [*From p.* 497.
39. Duplicate of Yoker, except condenser.	By gravity into small tip trucks on a 2ft. gauge railway in basement, finally charged into barges.
40.	Daily tests being made.
41.	In basement. 26 sq. ft. for 1 boiler; 34 sq. ft. for 2 boilers; 40 sq. ft. for 3 boilers.
42.	Steel. 2, one to each set of 3 boilers. 150ft 10ft. 73 sq. ft. 62ft. from base.
43.	160 lbs. per sq. in. Babcock & Wilcox. 6, for the 6000 kilowatt plant. 6, only 4 installed. 5730 sq. ft. 100 sq. ft. 20,000 lbs. of water per hour: feed at 60° F.

[*Continued on p.* 521.

Name of Generating Station	Radcliffe. [From p. 498.
39. **Ash Removal**	From bunkers into measuring shoots, thence into stoker hoppers.
Special Ash Railway	By gravity into ash trucks running on a light railway track in the basement.
Haulage in Basement	
Emptied into Barges by	
Stored in	
40. **Coal now used**	
Calorific Value	
Cost per ton	
41. **Boiler Flues**: Location	Under each row of boilers.
Flue Area	
42. Chimneys: Builders	
Material	Steel.
Number	2, one to each set of 3 boilers.
Height	150ft.
Diameter at top	
Area at top	
,, bottom	
Height of Firebrick Lining	
Foundations Dimensions	
,, Volume	
43. **Boilers**: Location	
Pressure	160 lbs. per sq. in.
Maker	Babcock & Wilcox.
Number	6.
Piped in sets of	
Heating Surface each	5700 sq. ft.
Grate Area each	100 sq. ft.
Number of Tubes in Width and Height	
Capacity	20,000 lbs. of water per hour, with feed at 80° F.

[Continued on p. 522.

Brimsdown. [*From p.* 499.	**English M'Kenna Process Co.**
39. By hand into coal conveyor.	
None.	
Conveyor.	
Cart at present. Ash bunker.	
40.	
12,000 B.Th.U. 11s. 9d.	
41. Back of Boilers on B.H. floor level.	
10ft. × 8ft. = 80 sq. ft.	
42. Piggott & Co. Steel.	Babcock & Wilcox Steel.
One. 160ft.	
10ft.	
78 sq. ft.	
160ft. Concrete 10ft. deep. Brick base 20 ft. above ground.	
43. One floor. Parallel with turbines.	
165 lbs. per sq. in. Babcock & Willcox.	165 lbs. per sq. in. Babcock & Wilcox.
6.	4 Babcock & Wilcox boilers and 8 Hyde waste-heat boilers, 250 H.P. supply steam through a 9-inch pipe to separately fired superheater.
4400 sq. ft. 56 sq. ft.	
15,000 lbs. per hour.	7500 lbs. water per hour.

[*Continued on p.* 523.

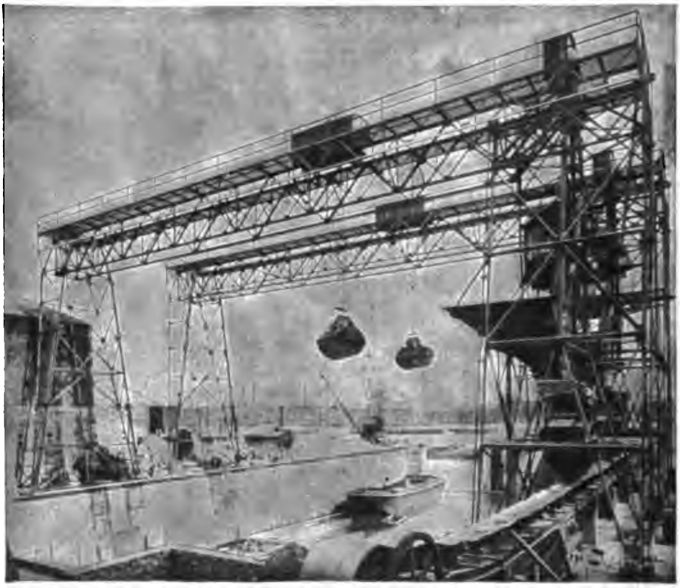


FIG. 371.

FIG. 372.

FIGS. 371, 372, and 373.—Lots Road, Chelsea: Coal-Receiving Arrangements at East Inclined Bucket Conveyor (item 34, p. 492).

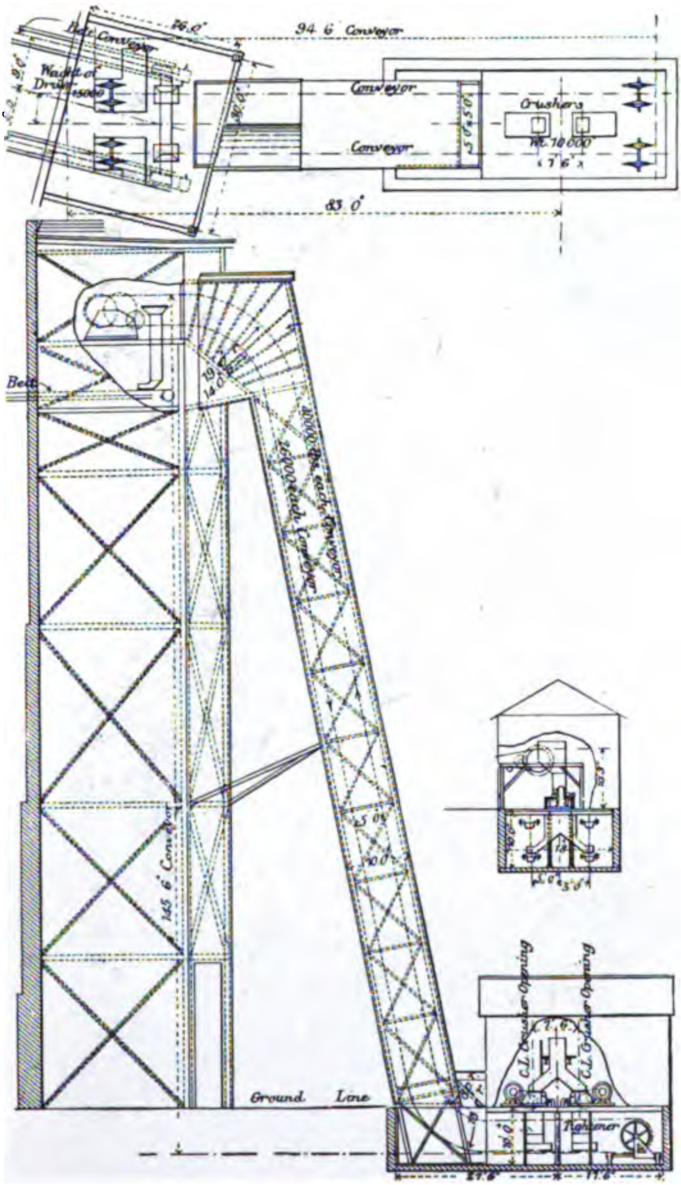


FIG. 373.

End of Power-House. Travelling Cranes span the Large Basin (item 31, p. 492). (*Tramway and Railway World.*)

Fig. 374.

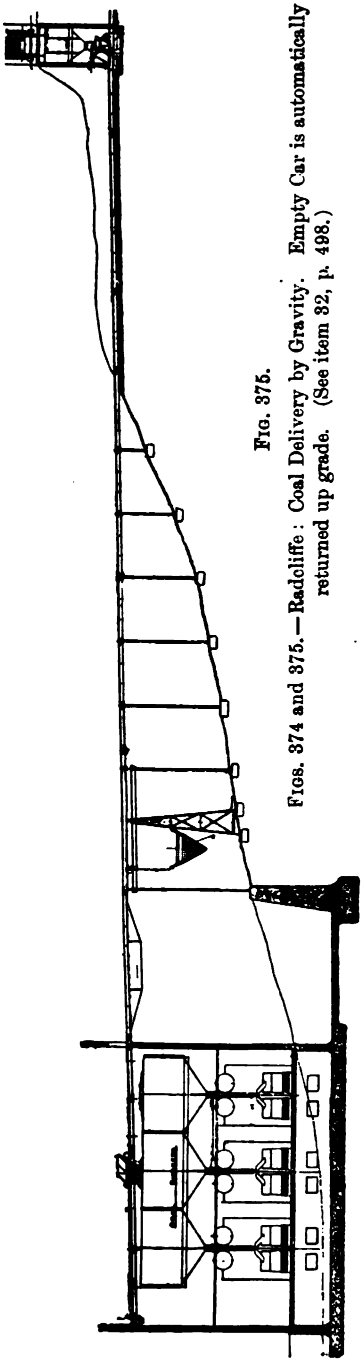


FIG. 375.

FIGS. 374 and 375.—Radcliffe: Coal Delivery by Gravity. Empty Car is automatically returned up grade. (See item 32, p. 498.)

FIG. 376.—Brimsdown: Coal-Receiving by Barge and Crane Grab, p. 499.

FIG. 377.—Brimsdown: Babcock & Wilcox Conveyor above Bunkers.

Fig. 378.

Figs. 378 and 379.—Brimsdown: Coal-weighing

FIG. 379.

Arrangements on arrival and before firing (item 32, p. 499).

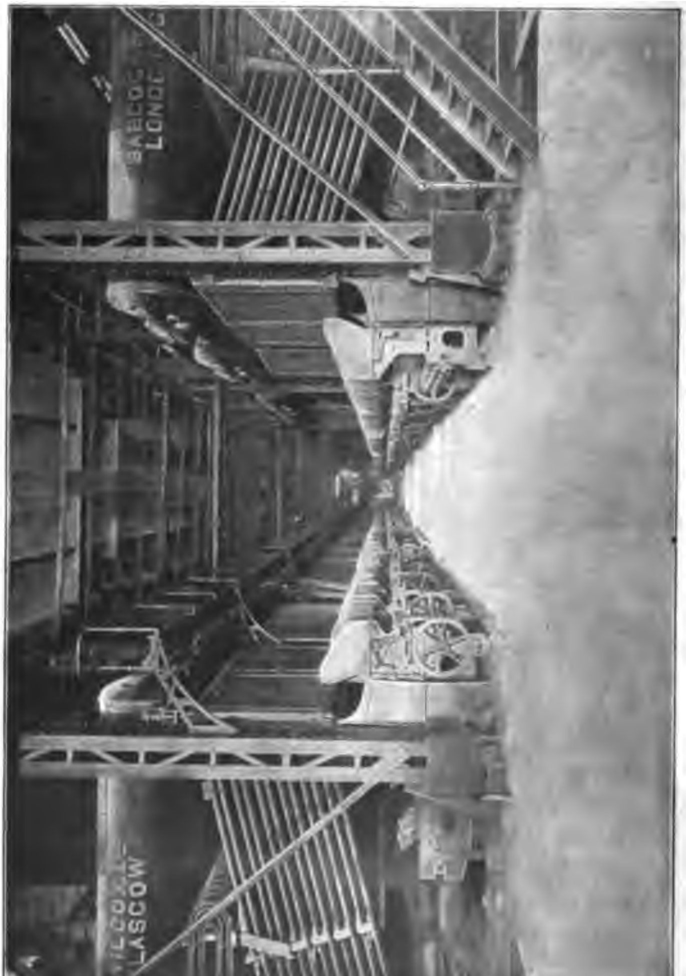


FIG. 380.—Lots Road, Chelsea: One of the Boiler-Houses.
(*Photo by Babcock & Wilcox.*)

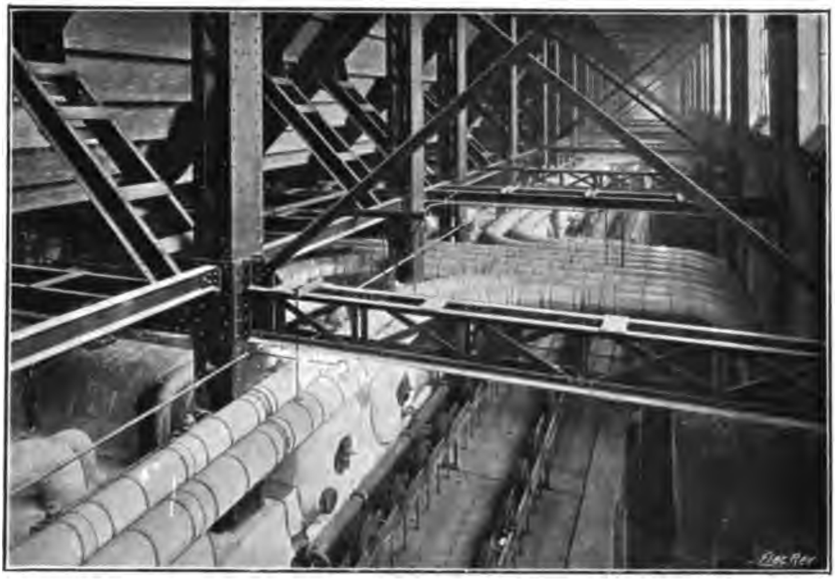


FIG. 381.—Lots Road, Chelsea: Piping from Eight Boilers to One Header. (*Photo by Elec. Review.*)

FIG. 382.—Lots Road, Chelsea: Feed Pump. (*Elec. Review.*)

Name of Generating Station	Lots Road, Chelsea. [*From p.* 500.
44. Mechanical Stokers	83 sq. ft. 'chain grate' each boiler.
Motor for Stokers	12, each 15 horse-power.
,, Type	Westinghouse C.B. 3 phase, 220 volts, 635 R.p.m., four lines of shafting under floor, 3 motors on each.
45. Superheater: Type	Babcock & Wilcox.
Superheating Surface each	672 sq. ft.
Degrees added	150° F.
Final Temperature	530° F.
46. Boiler Feed: Number of Mains	2, one on each boiler-room floor, Ring.
Diameter	
Feed Pumps connected to each	2, take supply from either of two pumps and feed either of two groups of boiler.
Pumps: Total number	8 in basement. Fig. 382 *ante*, p. 515.
Maker	7 Worthington Steam Pump Coy.
Type	Vertical Simplex Compound. 1 Heisler, Erie, Pa. triple expansion, with compensating valve gear.
Steam Cylinders	16½in. and 26in.; Worthington.
Stroke	18in.
Pump Plungers	2.
Diameter	9½in.
Overall Size	14ft. high by 8ft. wide.
Capacity each	18,000 gallons per hour.
Against	225 lbs. per sq. in.
Using Steam at	165 ,, ,,
Steam received from	
Steam exhausts to	Feedwater heater.
Steam consumed	1 lb. steam per 120 lbs. water delivered.
47. Economisers: Number	12 Greens, each 576 tubes.
Type	8 ,, 288 ,,
Number of Tubes	9216.
Length of Tubes	10ft. at 10¼in. and 12½in. centres.
Internal Diameter of Tubes	
Heating Surface for each Boiler	
Scrapers driven by	16 motors, one motor to each 576 tubes, of 3 horse-power, B.T.H. Co.'s type A.I.T., 3 phase, 220 volts, 955 R.p.m.
Thermometer for Feed Water	At each end of each group.

[*Continued on p.* 524.

[*From p.* 501.

Neasden.	Carville.	
44. Roney, 12ft. wide by about 7ft. deep.	Chain grate.	*With thermal storage boiler capacity 50,000 lbs. per hour for 2 hours per day. "Engineering," Nov. 4, 1905.*
Superseded now by chain grates.		
Westinghouse Engines.		
Single acting compound through worm gearing.		
45. Babcock & Wilcox.		
894 sq. ft.		
180° F.	150° F.	*150° F.*
560° F.		
46. 2 mains 7in. diam. from feed-pumps tapering to 4in. diam. at last boiler.	No oil-separating device.	
2 pumps, both connected to both mains.	1 to each set of 5 boilers.	
2.	3, one is spare.	
Weir.	Clark, Chapman & Co.	
Tandem compound.	Woodeson.	
	No oil used in cylinders.	
	No rings fitted to pistons.	
8in. and 14in.		
24in.		
Gun-metal.		
9in.		
16ft. height.		
20,000 gallons per hour (rated evaporation of all 10 boilers).	150,000 lbs. of water per hour.	
180 lbs. pressure.	200 lbs. per sq. in.	
180 lbs. per sq. in. superheated.		
12in. header.	Boilers by special pipe.	
Feed heaters.	Hotwell (through a spiral coil, where it is condensed).	
47. 1, E. Green & Son, Ltd., Manchester.	Green.	
1760.		
10ft.		
4in.		
184 sq. ft.		
5 horse-power 3 phase motor, 440 volts.	Motor.	

[*Continued on p.* 525.

Name of Generating Station	**Delray, U.S.A.** [*From p.* 502.
44. Mechanical Stokers	12 under each battery of 6 boilers. Roney.
Motor for Stokers	2 steam engines.
,, Type	
45. Superheater: Type	
Superheating Surface each	2000 sq. ft.
Degrees added	275° F. at boilers.
Final Temperature	
46. Boiler Feed: Number of Ring Mains	From hotwell into which condenser air pumps discharge.
Diameter	
Feed Pumps connected to each	Each battery of six boilers is fed by an independent pump.
Pumps: Total number	2, also on each boiler an International Injector for emergency use.
Maker	Worthington.
Type	Turbine centrifugal pump.
Steam Cylinder	Two 60 H.P. Induction motors.
Stroke	
Pump Plungers	
Diameter	8 inch.
Overall Size	
Capacity each	
Against	
Using steam at	
Steam received from	
Steam exhausts to	
Steam consumed	
47. Economisers: Number	8.
Type	Westinghouse patent circulating pattern by the Greene Fuel Econ. Co., with scraping gear.
Number of Tubes	104 sections of 12 tubes in each of 4 banks.
Length of Tubes	One economiser for 6 boilers.
Internal Diameter of Tubes	
Heating Surface for each Boiler	
Scrapers driven by	10 horse-power induction motors; flue gases enter 460° F., leave 200° F.; water from heaters at 175° F.
Thermometer for Feed Water	

[*Continued on p.* 526.

L. Street Boston, U.S.A.	**Quincy Point, Mass., U.S.A.** [*From p.* 503.
44. Roney.	The 8 Aultman & Taylor boilers have Jones under-feed stokers.
Induction type.	
45. Babcock & Wilcox. Internal.	Internal type. 8 Foster and 2 B. & W.
867 sq. ft.	
150° F.	65° F.
46.	The feed water is normally taken from the hot-water storage tanks which receive the condensed water from the condensers; it is then pumped through steam-driven Snow pumps to National type heaters.
1 to each turbine. Injector as stand-by.	
Duplex centre-packed plunger.	
47.	

[*Continued on p.* 527.

Name of Generating Station	**Yoker.** [*From p.* 504.
44. Mechanical Stokers	4 Roney stoker by Westinghouse Co.
Motor for Stokers	Through worm gearing by steam-engines.
,, Type	5 horse-power Westinghouse engines 400 R.p.m.
45. Superheater: Type	
Superheating Surface each	
Degrees added	150° F.
Final Temperature	
46. Boiler Feed: Number of Ring Mains	The feed water from hotwell, to which it is pumped from the condensers by a centrifugal pump driven by a vertical shaft motor.
Diameter	
Feed Pumps connected to each	
Pumps: Total number	2 in the basement.
Maker	J. P. Hall & Sons, Ltd.
Type	Tandem compound double-acting.
Steam Cylinders	
Stroke	
Pump Plungers	
Diameter	
Overall Size	
Capacity each	9600 gallons per hour.
Against	175 lbs. per sq. in.
Using steam at	
Steam received from	
Steam exhausts to	
Steam consumed	
47. Economisers: Number	1 to each pair of boilers; 1 in 2 sections.
Type	Green.
Number of Tubes	480 (*Engineer* stated 430 tubes).
Length of Tubes	10ft.
Internal Diameter of Tubes	
Heating Surface for each Boiler	
Scrapers driven by	
Thermometer for Feed Water	

[*Continued on p.* 528.

Motherwell.

44.

45.

46.

47. Duplicate of Yoker.

Thornhill. [*From p.* 505.

2 chain grates to each boiler.

7 horse-power, 600 R.p.m., 220 volts shunt wound, totally enclosed.

Babcock & Wilcox, Inside.

150° F.

2.

Hall.
Compound.

8000 gallons per hour.

200 lbs. per sq. in.

3in. diam. auxiliary header.

[*Continued on p.* 529.

[*From p.* 506.

Name of Generating Station	**Radcliffe.**
44. Mechanical Stokers	Chain grates.
Motor for Stokers	
,, Type	
45. Superheater: Type	Babcock & Wilcox. Inside.
Superheating surface each	508 sq. ft.
Degrees added	150° F.
Final Temperature	
46. Boiler Feed: Number of Mains	
Diameter	
Feed Pumps connected to each	
Pumps: Total number	2.
Maker	Messrs J. P. Hall & Sons, Ltd.
Type	Steam-pump, compound type.
Steam Cylinders	
Stroke	12in. × 20in. × 11¾in.
Pump Plungers	24in.
Diameter	
Overall Size	
Capacity each	10,000 gallons per hour.
Against	200 lbs. per sq. in.
Using Steam at	
Steam received from	
Steam exhausts to	
Steam consumed	
47. Economisers: Number	
Type	
Number of Tubes	
Length of Tubes	
Internal Diameter of Tubes	
Heating Surface for each Boiler	
Scrapers driven by	
Thermometer for Feed Water	

[*Continued on p.* 530.

Brimsdown. [*From p.* 507.	**Power Station of the English M'Kenna Process Co., Ltd.**
44. Chain grates.	4 inclined chain-grate stokers.
15 H.P.	8 horse-power 3 phase, through worm gearing.
c.c. worm drive.	Each pair of boilers has its own shafting, coupled to worm gearing by clutch.
45. Babcock & Wilcox. Internal.	4 internal superheaters, B. & W. ; also 1 independently fired superheater, B. & W., having capacity 120 F. of superheat to 45,000 lbs. of steam per hour.
508 sq. ft.	
145° F. (120° F. at turbo).	
46. Two.	
No oil-separating device.	
Yes.	
3.	2, one to each pair of boilers.
J. P. Hall & Sons, Ltd.	
Double-acting, vertical, compound.	A Hall slow-speed steam ; a Hayward Tyler 3-throw electrical.
7½ and 12½ diameter.	
15in.	
Gun-metal.	
7½in.	
8ft. × 2ft. × 2ft.	
4000 gallons per hour.	3500 gallons per hour.
165 lbs. per sq. inch.	
165 lbs. per sq. inch.	
Feed heater.	
47. None.	

[*Continued on p.* 531.

Name of Generating Station	**Lots Road, Chelsea.** [*From p.* 516.
48. Steam Piping:	
Each Boiler supplies Steam through	6in. solid drawn pipe to header.
Pipe Covering	
Pipe Flanges	Stamped steel screwed on and afterwards expanded.
Header	To each group of 8 boilers.
Maker of Pipes	Babcock & Wilcox.
49. Water Supply:	
Taken from	Storage tank on second floor of oil-cooling house.
Taken from Well	8½in. Artesian well by compressed air.
Depth of Well	575ft.
50. Auxiliary Water Supply	Town mains through ball-valve.
51. 2nd Auxiliary Water Supply	River water.
52. Main Steam Pipe to each Turbine	14ins. diam. lap-welded steel.
Main Steam Pipe to all Exciters	
Auxiliary Pipe	
Expansion taken by	Easy bend.
Flanges	Stamped steel, riveted.
53. Auxiliary Header	10ins. diam. for exciter engines.
Supplied from	3 of the main headers by 10in. diam. solid drawn steel pipe.
Expansion taken by	Easy bends.
Flanges	Stamped steel, riveted.
54. Condensed Steam from Condensers	Is fed into the high-level suction and falls through feed-water heaters into lower suction pipe, from which it is pumped through the economisers.
55. Feed-water Heaters get heat from Exhaust of	Boiler feed pumps; a sump is provided for condensed steam.
56. Main Steam Turbine	Figs. 383, 384, p. 540. See also pp. 140–4.
Type	Horizontal double-flow Westinghouse–Parsons.
Number	8.
Rated Output	5500 K.W.
Maker	British Westinghouse.
Speed	1000 revolutions per minute.

[*Continued on p.* 532.

[*From p.* 517.

	Neasden.	Carville.
48.		Minimum number of dissimilar parts.[1]
	7in. steel welded pipe.	Solid drawn mild steel pipe.
	Magnesium covering by Hobdell, Way & Co., London.	
	Welded steel.	Forged steel.
	,,	
	Piggott & Co., Birmingham.	
49.	2 Artesian wells.	
	First well, 32,000 gallons per hour capacity; second well, 15,000 gallons per hour capacity.	
	400ft. storage in a lake of 2 acres, 5ft. depth, and 6,500,000 gallons capacity.	
50.	Town mains.	
51.		
52.	10in. diam.	
	The Holly System of Drains is installed.	
	Large bends.	Large bends.
	Steel shrunk and welded.	
53.		
54.	Pumped to top of cooling towers; water from base of tower flows into lake.	
55.	Auxiliary pump engines.	
56.	Fig. 385, p. 542.	Fig. 355, *ante*, p. 475.
	Double-flow.	Parsons.
	4.	4.
	3500 K.W.	Two 2000 K.W., two 4000 K.W.[2]
	British Westinghouse.	C. A. Parsons & Co.
	1000 revolutions per minute.	1200 revolutions per minute. Max. varied 5 per cent.

[*Continued on p.* 533.

[1] Discussion by Mr J. H. Rosenthal on "Power Station Design," by Merz & McLellan, *Proc. Inst. E.E.*, p. 874, 28th Apr. 1904.

[2] Fig. 355 rates these at 3500 K.W.

Name of Generating Station.	**Delray, U.S.A.** [*From p.* 518.
48. **Steam Piping:**	
Each Boiler supplies Steam through	Steel pipe, extra heavy.
Pipe Flanges . . .	
Header	
Maker of Pipes . . .	
49. **Water Supply:**	
Taken from (Feed Pipes) .	Detroit River.
Taken from Well . .	
Depth of Well . . .	
50. **Auxiliary Water Supply** .	2 elevated tanks of 60,000 and 10,000 gallons capacity.
51. **2nd Auxiliary Water Supply** .	
52. **Main Steam Pipe to each Turbine**	
Main Steam Pipe to all Exciters	
Auxiliary Pipe . . .	
Expansion taken by . .	
Flanges	
53. **Auxiliary Header** . . .	
Supplied from . . .	
Expansion taken by . .	
Flanges	
54. Condensed Steam from Condensers	
55. Feed-water Heaters get heat from Exhaust of	Duplicate 8in. motor-driven Worthington low-pressure turbine pumps, each capable of supplying all the water, force the hotwell water through cast-iron mains to four 5000 horse-power Cochrane feed-water heaters.
56. **Main Steam Turbine** . .	Fig. 386, p. 543.
Type	Four-stage Curtis, vertical.
Number	4.
Rated Output . . .	3000 K.W.
Maker	General Electric, Schenectady.
Speed	

[*Continued on p.* 534.

	L. Street, Boston, U.S.A.	Quincy Point, Mass., U.S.A. [*From p.* 519.
48.	6in. diam. pipe; 8in. diam. pipe each pair of boiler; 12in. and 15in. diams. pipe increase with each pair.	
	Steam piping to turbine.	12 in. diam. main steam header.
49.	Hot-well feed-water piping, large flanged copper; feed-water piping, small screwed brass.	Feed piping over 3in. diam. is cast-iron, less than 3in. brass.
50.		City mains. (See item 69, p. 573.)
51.		
52.	15in. diam., 1·3 sq. ft. area, 2 branches 10in. diam., 5000 cu. ft. per min., 64ft. per sec. velocity.	
	6in. diam.; auxiliaries consume 5 per cent. of main unit.	
53.		
54.		
55.	Exhaust, all auxiliaries.	
56.	Figs. 388, 389, 390, p. 545.	Figs. 391, 392, 393, p. 548.
	Curtis.	Four-stage Curtis, vertical.
	2.	5.
	5000 K.W.	2000 K.W.
	General Electric Co.	General Electric Co. of Schenectady.

[*Continued on p.* 535.

[From p. 520.

Name of Generating Station	Yoker.
48. Steam Piping:	
Each Boiler supplies Steam through	
Pipe Flanges	
Header	
Maker of Pipes	
49. Water Supply:	
Taken from	City mains.
Taken from Well	
Depth of Well	
50. Auxiliary Water Supply	
51. 2nd Auxiliary Water Supply	River.
52. Main Steam Pipe to each Turbine	
Main Steam Pipe to all Exciters	
Auxiliary Pipe	
Expansion taken by	
Flanges	
53. Auxiliary Header	
Supplied from	
Expansion taken by	
Flanges	
54. Condensed Steam from Condensers	
55. Feed-water Heaters get heat from Exhaust of	An auxiliary heater by J. Wright & Co., 700 sq. ft. heating surface.
56. Main Steam Turbine	Figs. 394–5, p. 550, also pp. 146–7.
Type	Double-flow Westinghouse-Parsons.
Number	2. The engine-room will accommodate one more unit of 2000 K.W. and one of 3500 K.W.
Rated Output	3000 horse-power.
Maker	British Westinghouse.
Speed	1500 revolutions per minute.

[Continued on p. 536.

	Motherwell.	**Thornhill.** [*From p.* 521.
48.	Duplicate of Yoker	Mild steel, lap-welded, riveted branches 7in. diam. pipe into 12in. diam. main steam pipe, 2 separators at each end of steam ring. The steam through 12in. diam. separators into header parallel to engine-room.
49.		2 hotwells; they receive the discharge from the condensers.
		The arrangement of the steam and feed-water piping is designed so that one half of the boiler-house can be isolated from the other.
50.		
51.		
52.		8ins. diam. off main header.
		6ins. diam. to exciters; 3ins. diam. auxiliary to exciters.
		3ins. diam. underneath main header.
53.		3ins. diam. line over each set of boiler.
54.		
55		
56.		Figs. 397, 398, p. 553.
		Vertical Curtis.
		3.
		1500 K.W.
		British Thomson-Houston.
		1000 revolutions per minute.

[*Continued on p.* 537.

Name of Generating Station	Radcliffe. [From p. 522.
48. Steam Piping:	
Each Boiler supplies Steam through	
Pipe Flanges	
Header	
Maker of Pipes	
49. Water Supply:	
Taken from	
Taken from Well	
Depth of Well	
50. Auxiliary Water Supply	
51. 2nd Auxiliary Water Supply	
52. Main Steam Pipe to each Turbine	
Main Steam Pipe to all Exciters	
Auxiliary Pipe	
Expansion taken by	
Flanges	
53. Auxiliary Header	
Supplied from	
Expansion taken by	
Flanges	
54. Condensed Steam from Condensers	
55. Feed-water Heaters get heat from Exhaust of	
56. Main Steam Turbine	Figs. 399, 400, p. 555.
Type	Vertical Curtis.
Number	4.
Rated Output	1500 K.W.
Maker	British Thomson-Houston.
Speed	1000 revolutions per minute.

[*Continued on p.* 538.

	Brimsdown. *[From p.* 528.	**Power Station of the English M'Kenna Process Co., Ltd.**
48.	Ring or balancing main direct.	Electrically welded.
	W.S.	Electrically welded.
	Lap welded Steel.	10in., dropping to 8in., running along power-house.
	J. Spencer & Co.	Messrs Stewarts & Lloyds, Ltd.
49.	Well or Town mains.	15,000 gals. per hour to storage tank 60 ft. above ground level, by Alley & MacLellan, Ltd., steam driven air compressor (85 lbs. per sq. in.).
	20 ft.	400 ft.
50.	Metropolitan Water Board.	
51.		
52.	7 ins. diam.	6in. Holden & Brooke's traps drain the pockets electrically welded on the steam pipes.
	Expansion bend on main range.	
	14 ins. diam.	
53.	6 ins. diam.	
	Saturated steam valve or boilers.	
	Bend.	
	12 ins.	
54.	To hotwell by gravity, no filtering.	
55.	Pumps only.	
56.	Fig. 401, p. 557.	See pp. 488, 490.
	Horizontal parallel flow.	Willans-Parsons.
	3.	3.
		750 K.W. each at 0·8 power actor.
	Parsons.	
	1500 revolutions per minute.	1500 revolutions per minute.

[Continued on p. **539.**

Name of Generating Station	**Lots Road, Chelsea.**	[*From p.* 524.
Speed Control	10 per cent. above or below normal by electric control operated from control board.	
Bed-plate Dimensions	48ft. 1¼ins. by 11ft. 4ins.	
Height above Floor	13ft. 10ins.	
Platform Dimensions	4ft. 6ins. above floor, overhangs bed-plate.	
Foundation	50ft. by 15ft. by 39ft. deep each. See p. 442.	
Area	750 sq. ft.	
Steam Pressure	175 lbs. per sq. in.	
Superheat	100° F. at the turbine.	
Overload supplied	50 per cent. per automatic by-pass.	
57. Steam Consumption, lbs. per K.W.H.		
Guarantees with	165 lbs. per sq. in., 100° F. superheat.	
	26in. vacuum.	27in. vacuum.
At 25 per cent. overload	21·4 lbs.	18·3 lbs. per K.W.H.
Full load	20·9 lbs.	17·7 lbs. per K.W.H.
¾ load	23 lbs.	20·1 lbs. per K.W.H.
½ load	24·7 lbs.	21·4 lbs. per K.W.H.
¼ load		
Rotating portion	6ft. 5in. diam. rolled steel drum.	
Weights		
Peripheral Speed of Drum	336ft. per second.	
Main Bearings	Spherical cast-iron lined with babbitt.	
Cooled by	Water circulation.	
Quantity Water circulated	40 gallons per minute when required.	
Coupling to Generator	'Flexible claw' of forged steel running in oil.	
58. Steam Valves	The steam passes on its way to the turbine through the following:—Main disc-type stop valve, operated from platform by gearing.	
59. Emergency Governor	Operates at maximum speed an auxiliary valve, which in turn closes emergency shut-down valve. Through steam strainer.	
60. Centrifugal Governor	Geared to turbine shaft, operates a double-seat poppet valve through a small steam relay.	
61. After passing through the valves Steam enters	At middle, and passes in two directions through expanding nozzles.	

[*Continued on p.* 562.

Neasden.	Carville. [*From p.* 525.
Mechanical and electrical.	3 per cent. between "no-load" and normal load; 5 per cent. between "no load" and maximum load; 6 per cent. when running at maximum load.
	14·5ft.
See p. 442, Fig. 337. 41½ by 12 by 22ft. deep. 175 lbs. per sq. in. 180° F. at turbine. 25 per cent. for 6 hours with 26in. vacuum.	
57.	200 lbs., 150° F., 95 per cent. (28·5in.).
160 lbs. per sq. in. pressure, 27in. vacuum rated load.	15 lbs. per K.W.H. Merz & McLellan, *British Assn. Engineer*, 9/9/04.
17 lbs. per K.W.H.	18 lbs. per K.W., 4000 K.W. 19 lbs. per K.W., 2000 K.W.
20¼ lbs. per K.W.H.	
Turbine weighs 16½ tons; generator weighs 17 tons.	
18,000ft. per min.	
16in. diameter.	
Oil (under pressure) and water.	
1000 gallons per hour.	
58. By Fletcher & Co., Ashton-under-Lyne.	
59. Controls speed 10 per cent. above normal; position on end of main shaft.	
60. Worm gear (ratio 10 to 1) from main shaft, controlled by electricity from switchboard.	Ordinary governor supplemented by special governor and valve to admit high-pressure steam to low-pressure turbine for overloads.
61.	

[*Continued on p.* 563.

Name of Generating Station	Delray, U.S.A. [*From p.* 526.
Speed Control	
Bed-plate Dimensions	
Height above Floor	
Platform Dimensions	
Foundation	
Area	
Steam Pressure	200 lbs. per sq. in.
Superheat	200° F.
Overload supplied	
57. Steam Consumption, lbs. per K.W.H.	
Guarantees with	
At 25 per cent. overload	
Full load	
¾ load	
½ load	
¼ load	
Rotating portion	
Weights	
Peripheral Speed of Drum	
Main Bearings	
Cooled by	
Quantity Water circulated	
Coupling to Generator	
58. Steam Valves	12 poppet valves on each side, controlled by magnets.
59. Emergency Governor	
60. Centrifugal Governor	
61. After passing through the valves Steam enters	

[*Continued on p.* 564.

L. Street Station, Boston, U.S.A.

514 revolutions per minute.

50 per cent. for two hours.

57. From item 52, *ante*, 3 cu. ft. per lb., *Power*, July '05. This equals 20 lbs. per K.W.H., 175 lbs. per sq. in., 150° F. superheat, vacuum not stated here.

13ft. diam.

68 tons revolving.
350ft. per second.

Footstep-bearing, lubricated with water at 900 lbs. per sq. in.
2 duplex steam-driven pressure pumps; 1 triplex motor-driven spare pump.
10 minutes supply accumulator capacity; 136,000 lbs. weight on feetstep.

58. 15 steam nozzles each side.

59. Emergency auto-valve connects to 30in. atmospheric exhaust.

60.

61.

Quincy Point, Mass., U.S.A.

[*From p.* 527.

750 revolutions per minute.

200 lbs. per sq. in.

Coal consumption 2·94 lbs. p. K.W.H., showing an efficiency of 8·36 per cent.

Water step-bearing.

[*Continued on p.* 565.

Name of Generating Station .	Yoker. [From p. 528.
Speed Control . . .	20,000 blades each turbine.
Bed-plate Dimensions. .	
Height above Floor . .	
Platform Dimensions . .	
Foundation. . . .	
Area	
Steam Pressure . . .	
Superheat	
Overload supplied . .	3750 horse-power overload capacity.
57. Steam Consumption, lbs. per K.W.H.	
Guarantees with . . .	
Full load	
¾ load	
½ load	
¼ load	
Rotating portion . .	
Weights	
Peripheral Speed of Drum .	
Main Bearings . . .	440 ft. per sec.
Cooled by	
Quantity Water circulated .	
Coupling to Generator .	Direct-connected.
58. Steam Valves . . .	
59. Energency Governor . .	
60. Centrifugal Governor . .	
61. After passing through the valves Steam enters .	

[Continued on p. 566.

Motherwell.

57.

Duplicate of Yoker, except condensers.

58.

59.

60.

61.

Thornhill. [*From p.* 529.

3 per cent. up or down by electrical switch, which cannot stay 'in' unless the operator's hand is on it.

See Fig. 337, p. 442.

Guarantee.		Tests.	
Pressure Superheat Vacuum.	160 lbs. zero. (?)	150 lbs. Dry 28 in.	150 lbs. 200° F. 28 in.
20·5	...	19	16
...	...	19·8	16·6
22	...	21·8	18·2
...	...	25·6	21·2

Water footstep.

"Curtis" type, described p. 198.

[*Continued on p.* 567.

[*From p.* 530.

Name of Generating Station	**Radcliffe.**
Speed Control	
Bed-plate Dimensions	
Height above Floor	
Platform Dimensions	
Foundation	
Area	
Steam Pressure	
Superheat	
Overload supplied	
57. Steam Consumption, lbs. per K.W.H.	
Guarantees with	Tested at maker's works; 150 lbs. pressure and 100° superheat and 28in. vacuum; 16·4 lbs. per K.W.H.
At 25 per cent. overload	
Full load	
¾ load	
½ load	
¼ load	
Rotating portion	
Weights	
Peripheral Speed of Drum	
Main Bearings	
Cooled by	
Quantity Water circulated	
Coupling to Generator	
58. **Steam Valves**	
59. **Emergency Governor**	
60. **Centrifugal Governor**	
61. **After passing through the valves Steam enters**	

[*Continued on p.* 568.

Brimsdown. [*From p.* 531.	Power Station of the English M'Kenna Process Co., Ltd.
Suspension spring on governors.	
150 lbs. per sq. in. at stop valve. 150° F. 25 per cent.	150 lbs. per sq. in. at stop valve. 100° F. superheat.
57.	
11,300 ft. per minute at last expansion. White metal.	
Not cooled.	
Toothed coupling.	
58. Stop, Emergency, and Double Beat.	Hartnell type.
59. Parsons.	
60. Parsons.	
61.	

[*Continued on p.* 569.

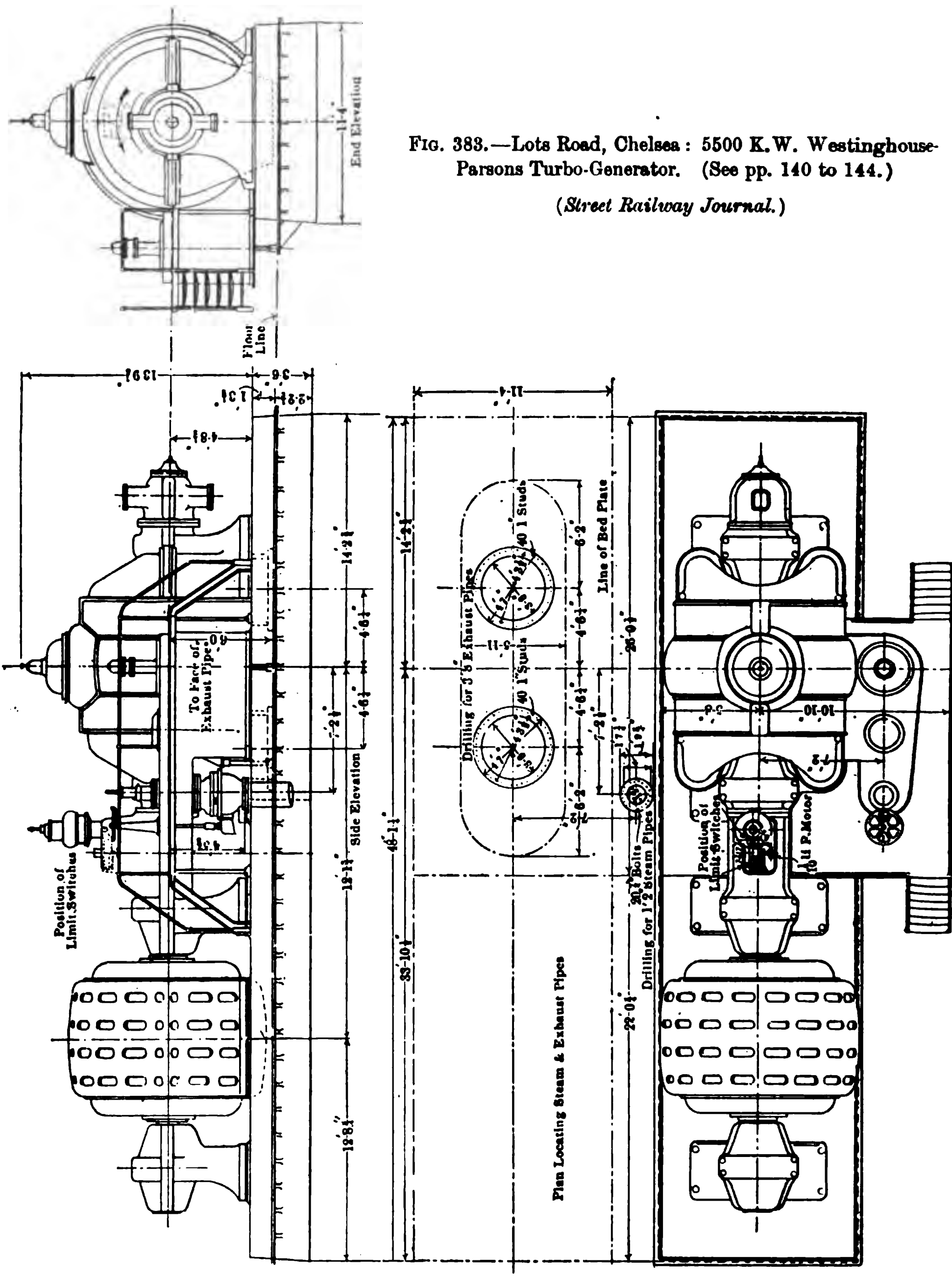
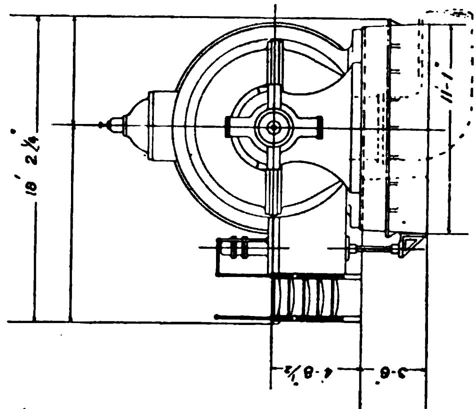


FIG. 383.—Lots Road, Chelsea: 5500 K.W. Westinghouse-Parsons Turbo-Generator. (See pp. 140 to 144.)

(*Street Railway Journal.*)

FIG. 384.—Lots Road, Chelsea: Turbine-Room, showing Exciters at the left-hand side.



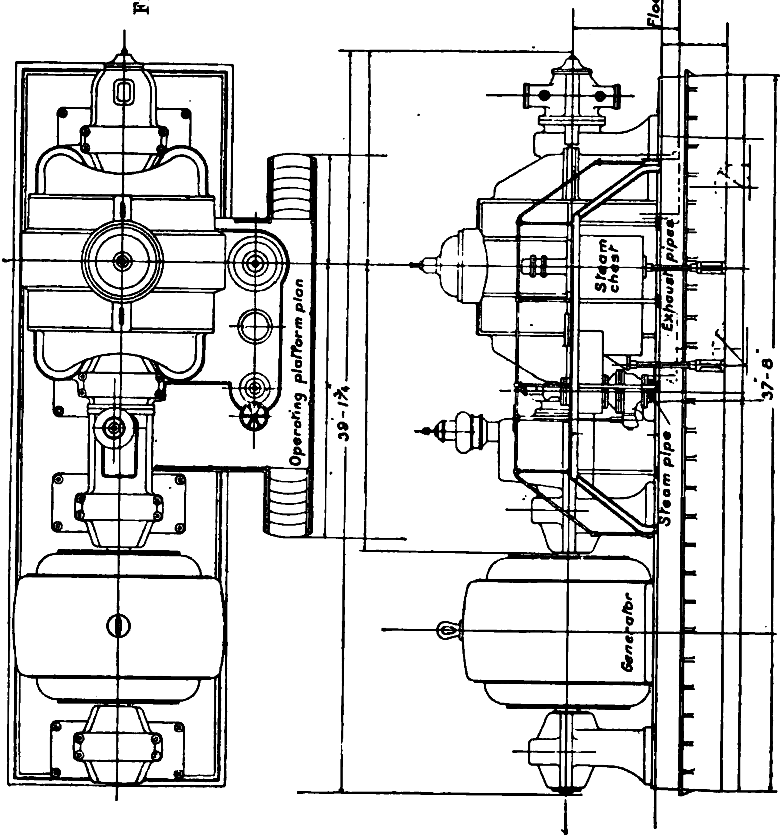


FIG. 385.—Neasden: 3500 K. W. Westinghouse-Parsons Turbo-Generator.

(*Tramway and Railway World.*)

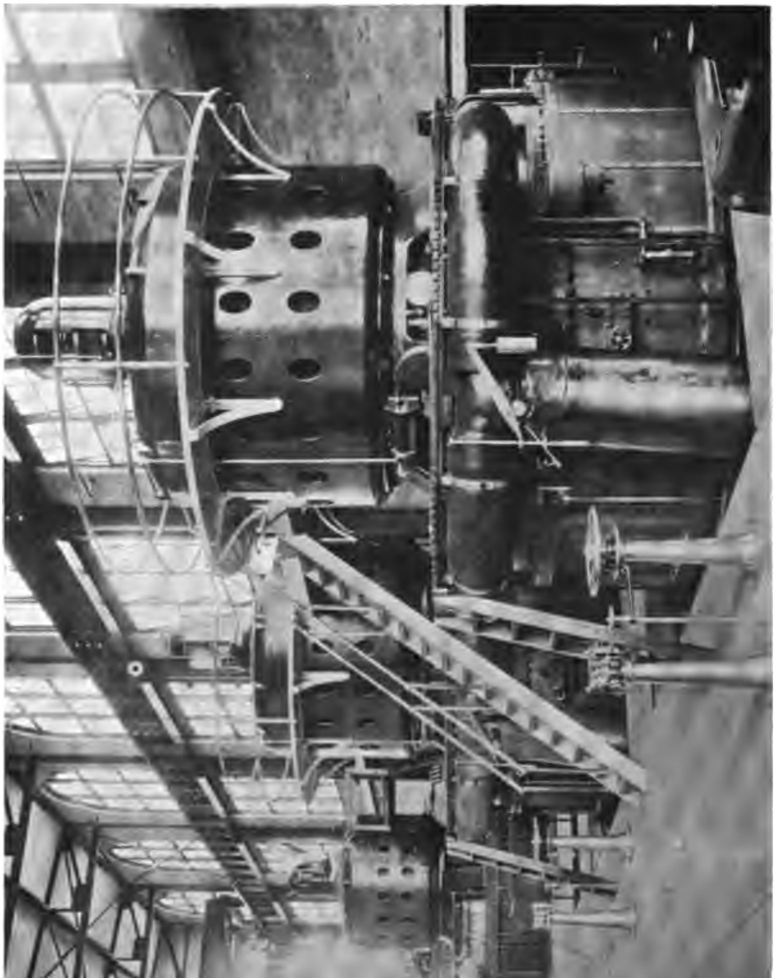


FIG. 386.—Delray, Detroit Edison Co.

Three 3000 K.W., 12 Pole, 3 Phase, 60 Cycles, 600 R.p.m. Generators and Curtis 4 Stage Steam Turbines.

(Photo from G.E. Co. of New York.) (See p. 526.)

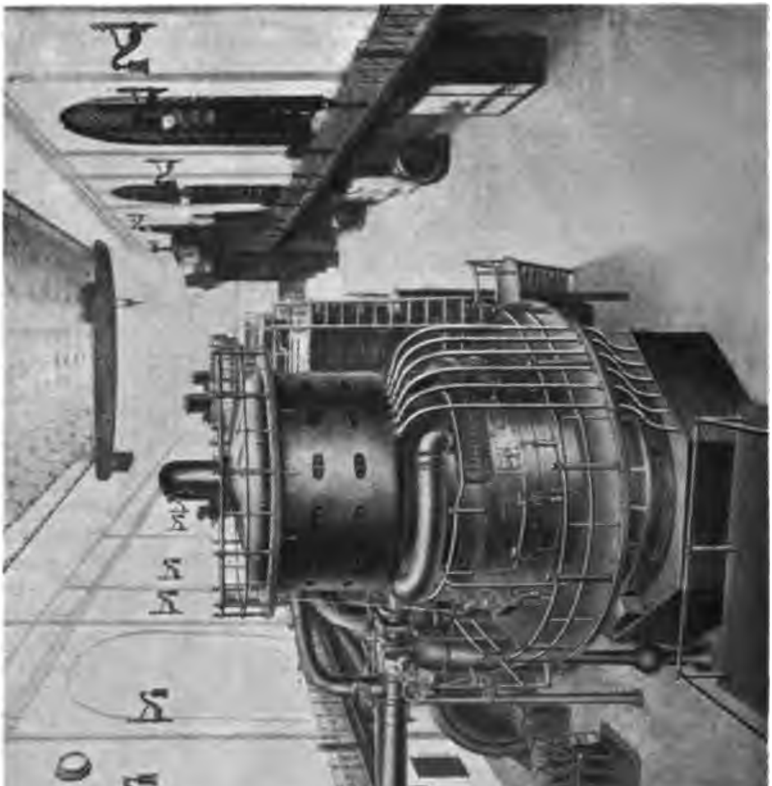


FIG. 387.—Chicago Edison Co.: Installed Oct.-Dec. 1903 and Apr. 1904.
Three 5000 K.W., 9000 Volts, 25 Cycles, 3 Phase Alternators and Curtis Steam Turbines, 500 R.p.m.
(G.E. Co. of New York.)

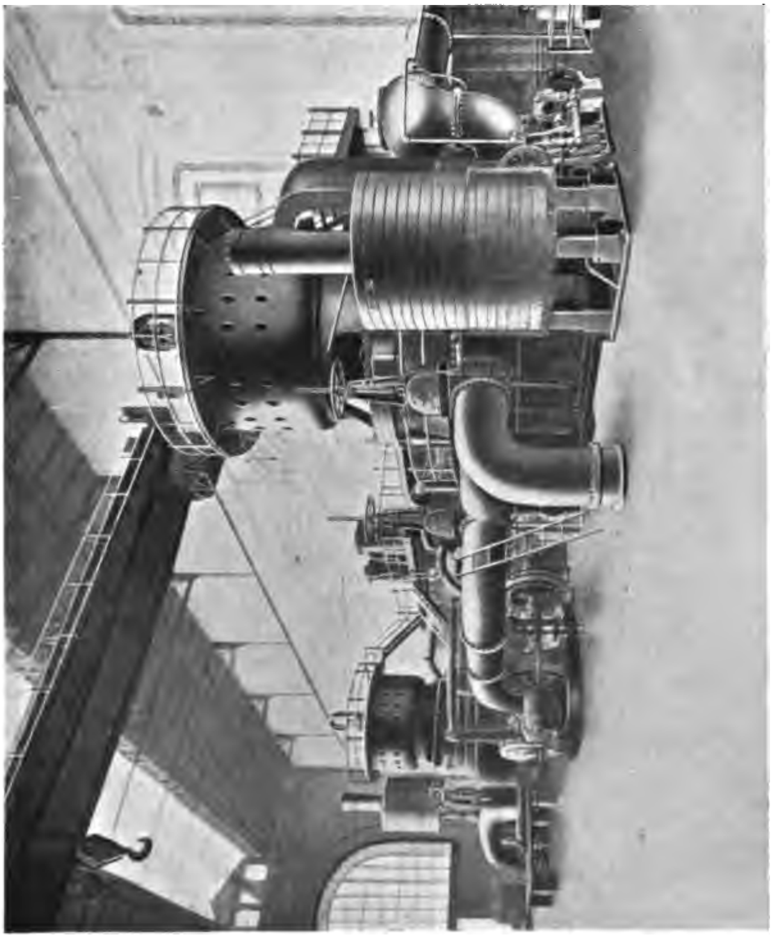


FIG. 388.—Boston Edison Co.: Installed Oct. and Nov. 1904.

Two 5000 K.W., 6900 Volts, 60 Cycle Alternators and Curtis Steam Turbines with Subbase Condensers. These Accumulators supply Oil to Footstep Bearings in emergencies. (See Figs. 389 and 390.)
(Photo from G.E. Co. of New York.) (See p. 527.)

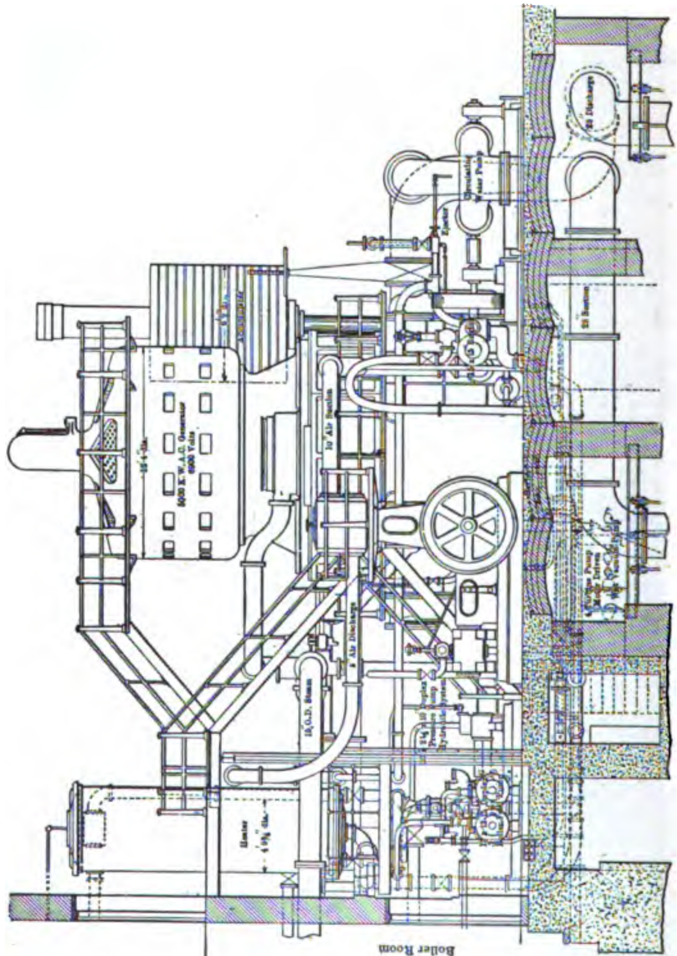


FIG. 389.—Boston Edison 5000 K. W. Curtis Turbo-Generator : Elevation.

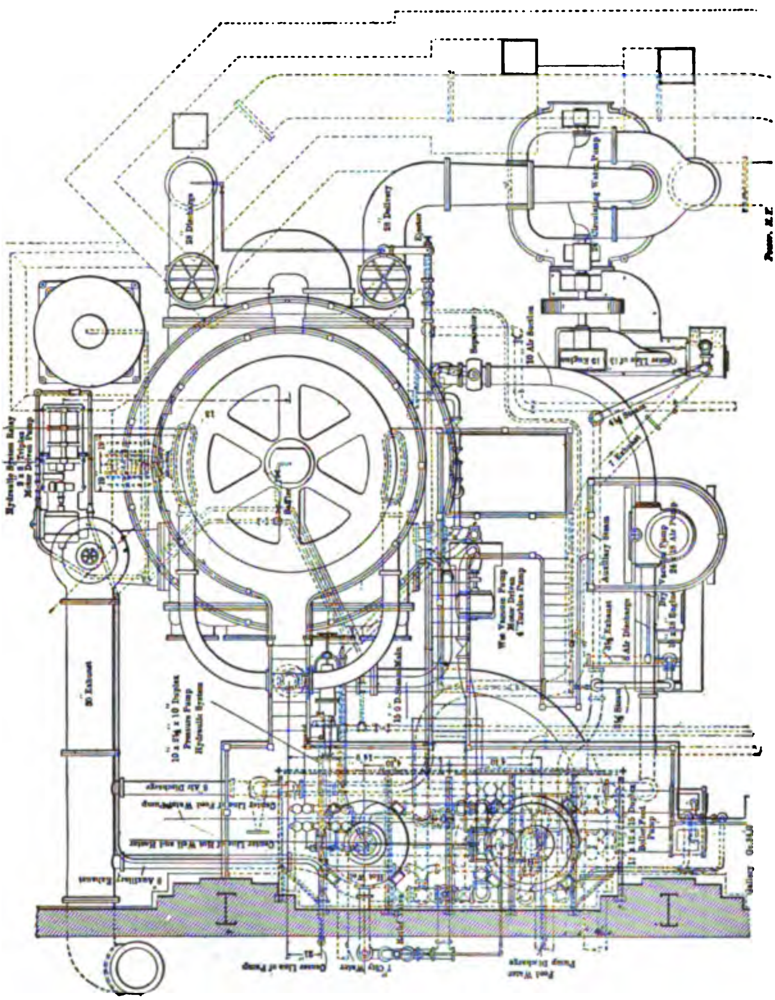


FIG. 390.—Boston Edison 5000 K.W. Curtis Turbo-Generator: Plan.

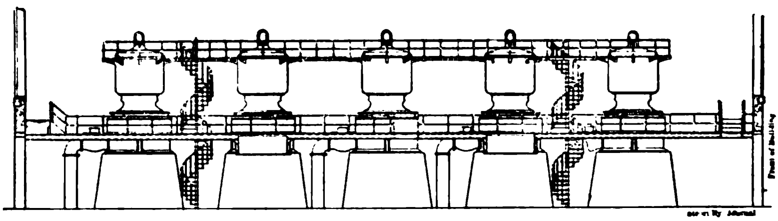


FIG. 391.—Quincy Point: Turbine Platforms, p. 527.

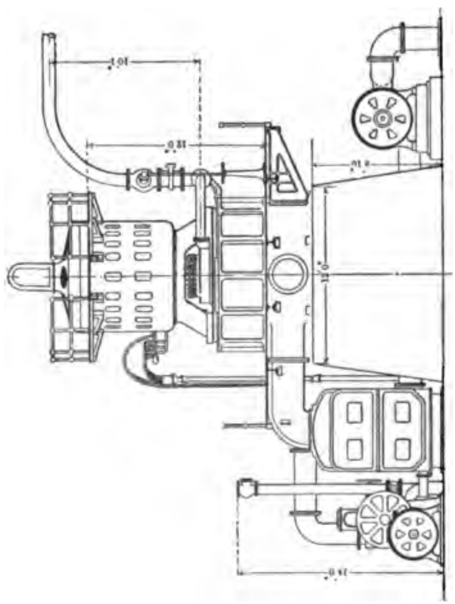


FIG. 392.—Quincy Point: 2000 K.W. Dimensioned Elevation.

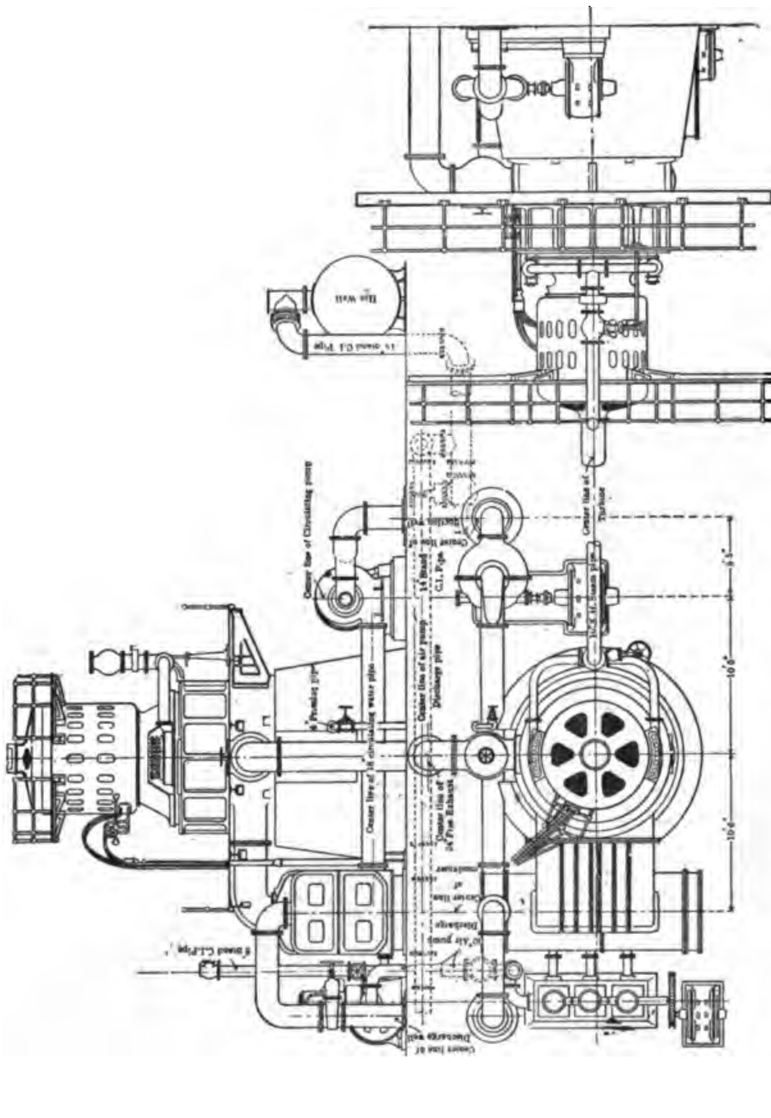


FIG. 393.—Quincy Point: 2000 K. W. Curtis Turbo-Generator. Three Views. (*Street Railway Journal.*)

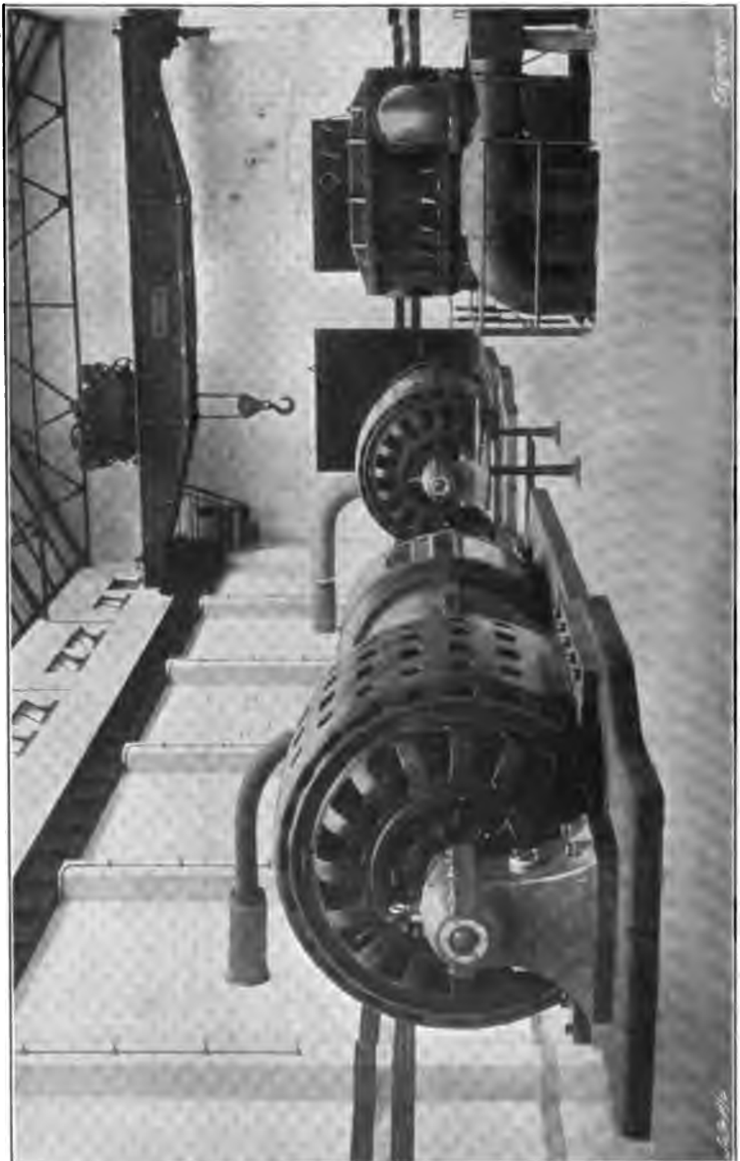


FIG. 394.—Yoker: Main Generating Sets and Condenser. (*The Engineer.*) Page 528.

FIG. 395.—Yoker: 2000 K.W. 1500 R.p.m. Set. (See pp. 146-7.)

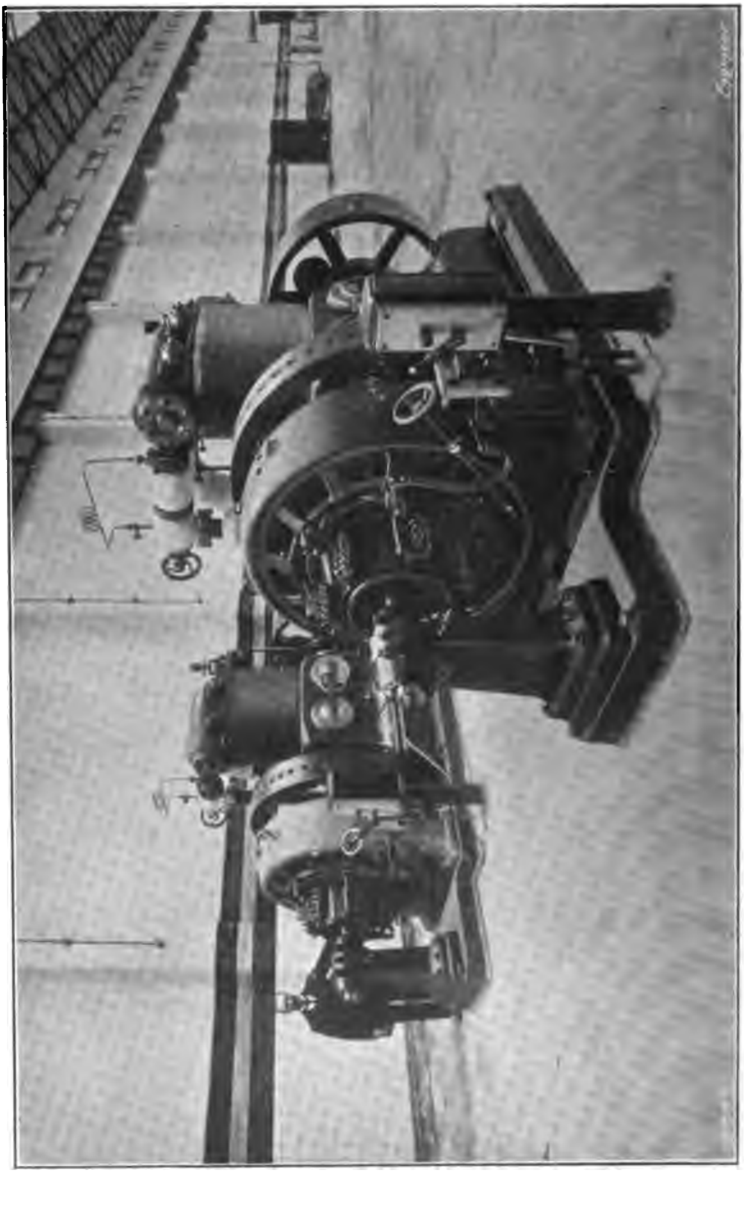


FIG. 396.—Yoker: Exciter Sets. (*The Engineer.*)

FIG. 397.—Thornhill: 1500 K.W. Curtis Set. Condenser at right hand.

(*The Electrical Review.*)

Fig. 398.—Thornhill: Exciters.

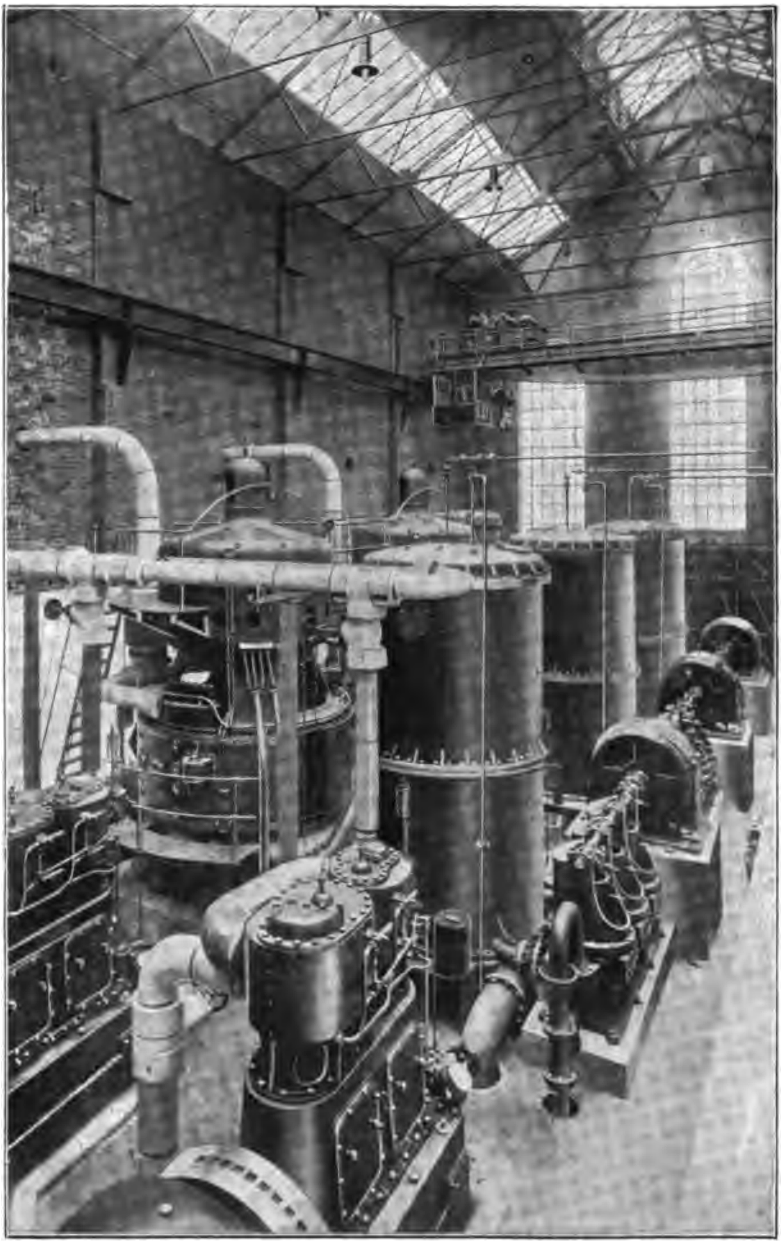


Fig. 399.—Radcliffe: Interior of Turbine-Room. 1500 K.W. Units.

(*The Elec. Engr.*)

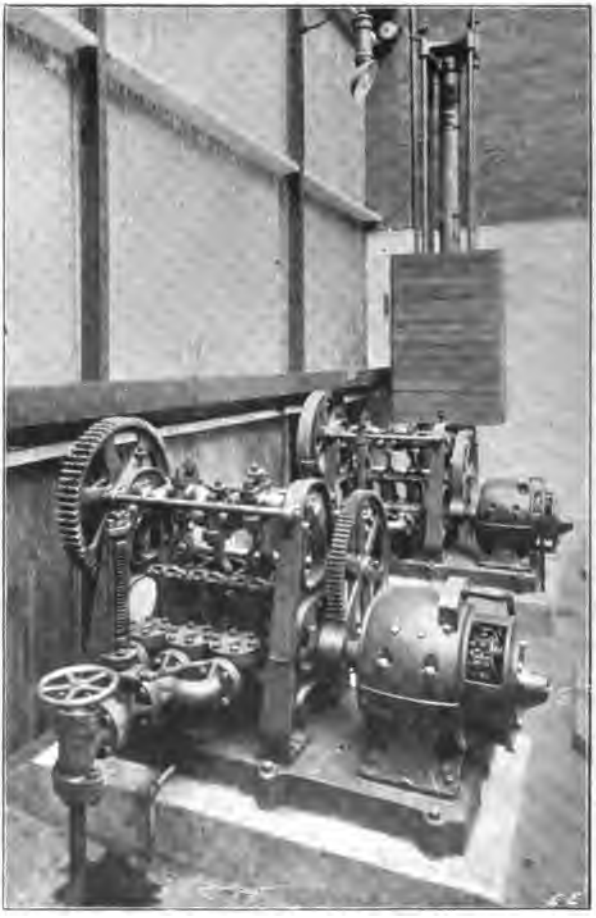


FIG. 400.—Radcliffe: Water Accumulator and Pumps for Footstep Bearings. (See item 63, Thornhill, p. 567.)

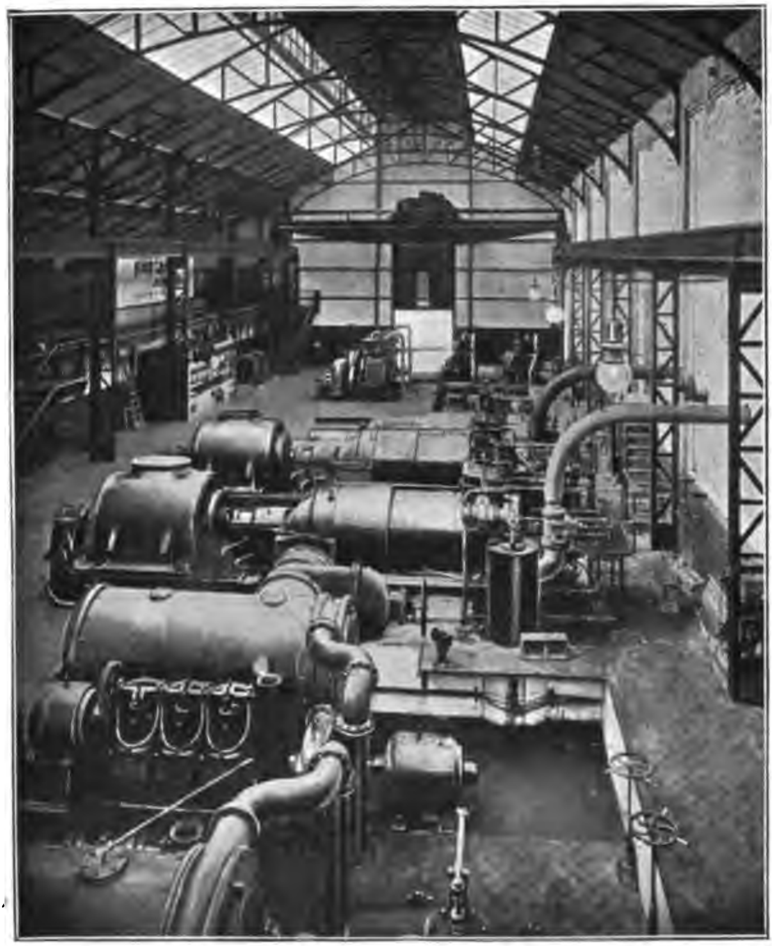


Fig. 401.—Brimsdown Turbine-Room and Switchboards.
H.T. Switchboard on gallery: L.T. on floor level.

FIG. 402.—Fulham, London: 750 K.W. Curtis Turbo-Alternator.
(See p. 437.)

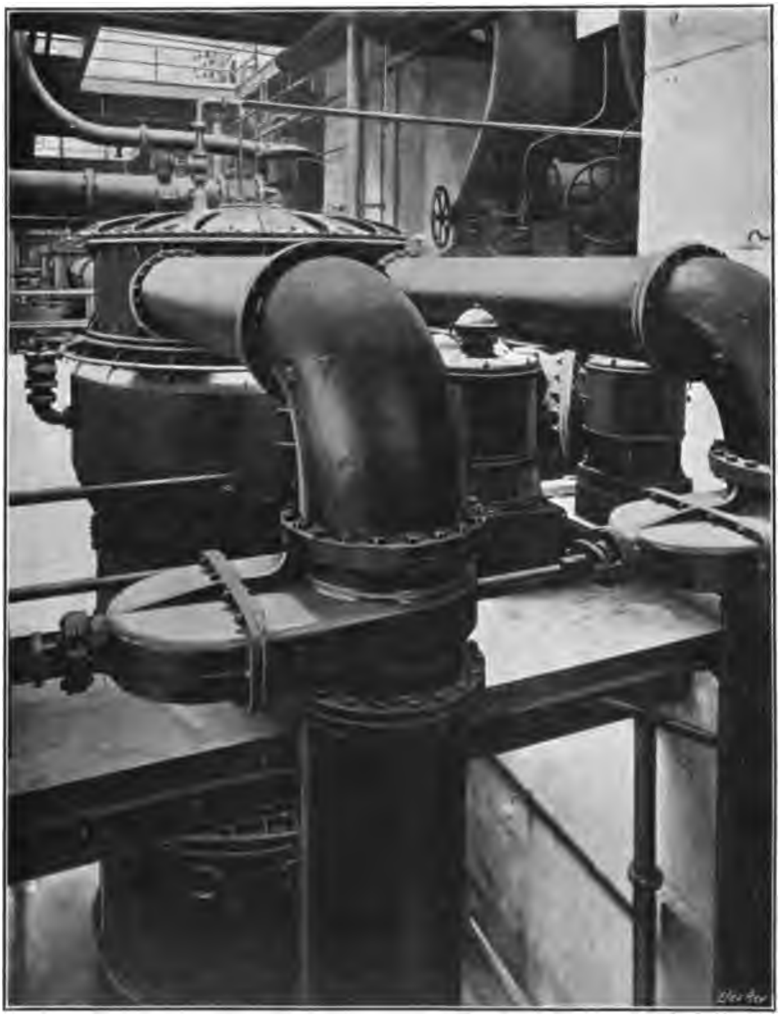


FIG. 403.—Lots Road, Chelsea: Condenser. (See Fig. 350, p. 470.)
(Photo by *Elec. Review.*)

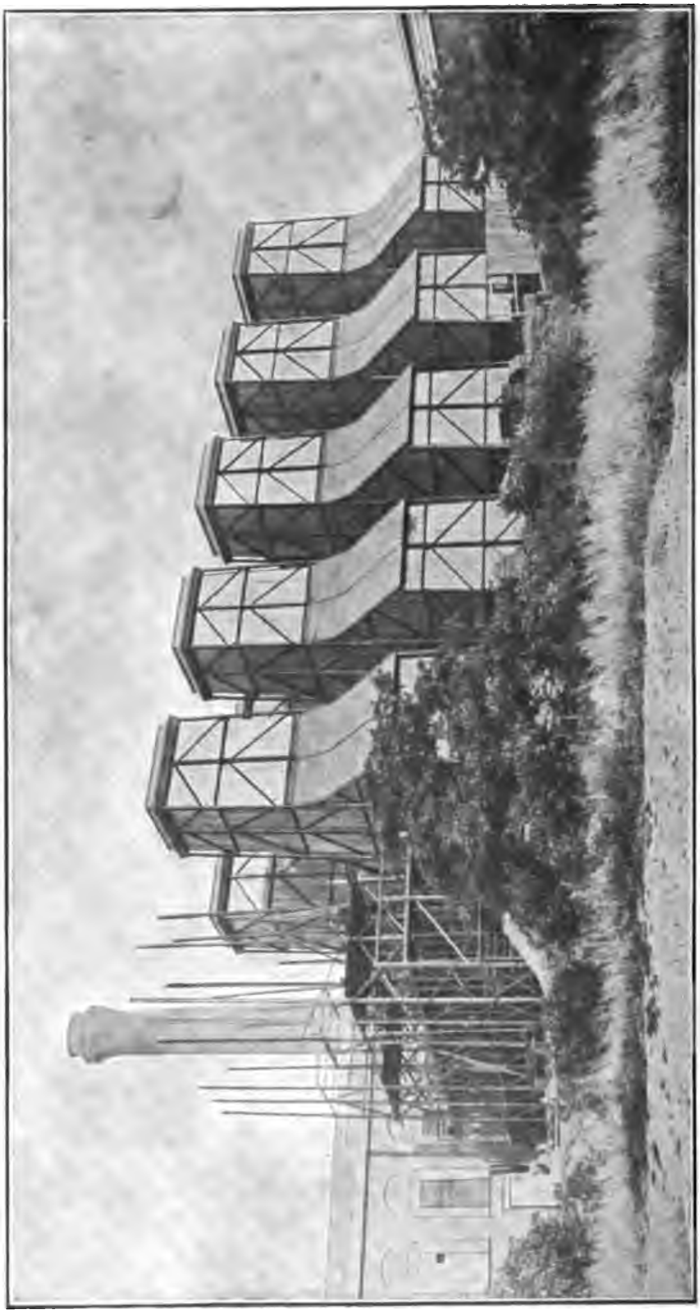


FIG. 404.—Neasden: Five of the Six Duplex Zschocke Cooling Towers. Capacity 1,600,000 Gals. per Hour. (See p. 486.)

Fig. 405.—Elevated Counter Current Jet Condenser.

Motherwell Station, Clyde Valley E.P. Co.*, 80,000 *lbs. steam per hour.

(*Mirrlees Watson Co.*) **[See p. 575.**

Name of Generating Station	Lots Road, Chelsea. [*From p.* 532.
62. First Series of Impulse Vanes	Drop forged steel.
Lowest Pressure Vanes	Delta metal.
63. **Lubrication**	Centrifugal system under
Pressure	30ft. head.
Quantity passed through Bearings of one Turbine Unit	33 gallons per minute.
Total Capacity of Plant	350 gallons per minute.
Water-cooling Jacket	40 gallons per minute.
64. **Oil-cooling Plant**	
Position	Separate building.
Capacity	20,000 gallons.
Maker	James Simpson & Co., Ltd.
2nd floor	Feed-water storage tank.
3rd floor	Oil-filtering tanks.
Height of Gravity Tank	30ft. above level of turbine bed.
Oil Pipe to Engine-room	6ins. diam. ring main.
Oil Discharge	By gravity to basement.
Oil Coolers: Number	3.
Surface each	686 sq. ft. brass tubes.
Oil pumped by	3 centrifugal pumps.
Driven by	3 motors, each 7½ horse-power, 220 volts, 3 phase, 955 revolutions per minute.
Cooling water pumped by	3 pumps.
Driven by	3 motors, each 3 horse-power, 220 volts, 3 phase, 635 revolutions per minute.
Oil delivered	
65. **Atmospheric Exhaust**	4.
Size and Position	60in. diam. against each chimney, up through roof.
Valve	Air-controlled type.
66. **Turbine Exhaust** to Condenser each	21 sq. ft. total (two 44in. diam. openings).
67. **Condensers**: **Type**	Vertical surface. Fig. 403, *ante*, p. 559.
Maker	James Simpson & Co., Ltd.

[*Continued on p.* 570.

Neasden.

Carville. [*From p.* 533.

62. Drop forged steel.
Hard drawn delta metal.

63. Oil.

15 lbs. per sq. in.

64.
North-end engine-room, basement.

34ft. above bearings.
$4\frac{1}{2}$ins. diam.
Into coolers through 6in. pipe.
2.
3000 sq. ft.
Worthington steam-pump.

Lake and back again.

Back to gravity tank.

65. Automatic.
6ft. diam.

Gravity valves.

66. 15·9 sq. ft., 2000 K.W.
24 sq. ft., 3500 K.W.

67. Barometric jet. Exhaust steam pipe each, 54in. approx.; barometric pipe each, 22in. approx.; water pipe, 18in. approx.; air pipe, 5ft. 9in. diam.; condenser proper, 8ft. high.
Alberger design, built by British Westinghouse Co.

Carville: Surface condenser and vacuum augmenter to each set.

[*Continued on p.* 571.

Name of Generating Station	**Delray, U.S.A.** [*From p.* 534.
62. First Series of Impulse Vanes	
Lowest Pressure Vanes	Between the first and second stages is an automatic by-pass valve, and a hand operated by-pass between 2nd and 3rd stages.
63. Lubrication	Step-bearing with water; steady-bearing with oil.
Pressure	650 lbs. per sq. in. of water, pumped by 2 steam pumps 10ins. by $2\frac{1}{2}$ins. by 12ins., made by Deane Brothers, Indianopolis, to a hydraulic accumulator by R. D. Wood & Co. A reserve is afforded by 2 electric pumps driven by 5 horse-power motors.
Quantity passed through Bearings of one Turbine Unit	Each step-bearing requires 4 gallons water per minute.
Total Capacity of Plant	
Water-cooling Jacket	
64. Oil-cooling Plant	
Position	
Capacity	
Maker	
2nd floor	
3rd floor	
Height of Gravity Tank	
Oil Pipe to Engine-room	
Oil Discharge	
Oil Coolers: Number	
Surface each	
Oil pumped by	2 Blake pumps, 3 by 2 by 3ins., pumping from 2 tanks in the basement to a tank in the gallery.
Driven by	
Cooling water pumped by	
Driven by	
Oil delivered	
65. Atmospheric Exhaust	
Size and Position	
Valve	
66. Turbine Exhaust to Condenser each	When the exhaust steam is not used for the evaporation of salt, it is taken direct to condensers.
67. Condensers: Type	Wheeler surface.
Maker	

[*Continued on p.* 572.

	L. Street Station, Boston, U.S.A.	**Quincy Point, Mass., U.S.A.** [*From p.* 535.
62.		
63.	Footstep: water 900 lbs. per sq. in. Accumulator supplies water during 10 minutes. A triplex motor-driven pump in reserve.	Water footstep bearing: 3 steam-driven pumps and 2 accumulators carry 10 minutes' supply.
	Through filter: Fig. 359 near "Turbine Room."	
64.		For water to step-bearings of the turbines there are 3 steam-driven pumps and 2 accumulators.
65.	30in. diam.	
66.		
67.	Surface.	'Admiralty' surface.
	Worthington.	Wheeler Condenser & Engineering Co.

[*Continued on p.* 573.

[*From p.* 536.

Name of Generating Station .	**Yoker.**
62. First Series of Impulse Vanes .	Drop forged steel.
Lowest Pressure Vanes .	Special metal.
63. **Lubrication**	
Pressure	The oil is pumped by a special oil pump to a tank in the roof of boiler-house, and flows by gravity under a head of 50ft. to the bearings.
Quantity passed through Bearings of one Turbine Unit	
Total Capacity of Plant .	A large tank in basement of engine-room, with supply of oil which should last one to two years.
Water-cooling Jacket . .	
64. **Oil-cooling Plant** . . .	
Position	
Capacity	
Maker	
2nd floor	
3rd floor	
Height of Gravity Tank .	
Oil Pipe to Engine-room .	
Oil Discharge . . .	
Oil Coolers: Number . .	
Surface each . .	
Oil pumped by . . .	
Driven by	
Cooling water pumped by .	
Driven by	
Oil delivered . . .	
65. **Atmospheric Exhaust** . .	
Size and Position . .	
Valve	
66. **Turbine Exhaust** to Condenser each	
67. **Condensers**: **Type** . . .	Vertical surface
Maker	Mirrlees-Watson Co.

[*Continued on p.* 574.

Motherwell	Thornhill. [*From p.* 537.
62.	
63.	Footstep with water, the top and centre bearing with oil.
	450 lbs. per sq. in. of water; 10 lbs. per sq. in. of oil. Water is supplied from a Berry hydraulic accumulator, in connection with which there are installed two three-throw force pumps geared from 7·5 horse-power B.T.H. Co. shunt-wound motors.
64.	
	On top of engine-house.
	Into settling-tank in basement.
	Force pumps in the basement.
	The accumulator pumps above.
65.	30ins. diameter.
66.	11 sq. ft. (nearly).
67. Barometric jet. See Fig. 405, p. 561.	Vertical surface.
Mirrlees-Watson Co.	Mirrlees-Watson & Co., Ltd.

[*Continued on p.* 575.

[*From p.* 538.

Name of Generating Station	Radcliffe.
62. First Series of Impulse Vanes .	
Lowest Pressure Vanes .	
63. Lubrication	400 lbs. per sq. in. of water drawn from air-pump discharge.
Pressure	Fig. 400, p. 556.
Quantity passed through Bearings of one Turbine Unit	7½ gallons water per minute.
Total Capacity of Plant .	¾ gallon oil to other bearings.
Water-cooling Jacket .	
64. Oil-cooling Plant . . .	
Position	
Capacity	
Maker	
2nd floor	
3rd floor	
Height of Gravity Tank .	
Oil Pipe to Engine-room .	
Oil Discharge . . .	
Oil Coolers: Number . .	
Surface each . .	
Oil pumped by . . .	
Driven by	
Cooling water pumped by .	
Driven by	
Oil delivered . . .	
65. Atmospheric Exhaust . .	
Size and Position . .	
Valve	
66. Turbine Exhaust to Condenser each	
67. Condensers: Type . . .	Surface. Vertical.
Maker	

[*Continued on p.* 576.

Brimsdown. [*From p.* 539.	**Power Station of the English M'Kenna Process Co., Ltd.**
62. Special alloy.	
" "	
63. Forced. 8 to 12 lbs. per sq. in.	
30 gallons per minute.	
64. Ground floor at side of turbine.	
3.	
Worm on turbine.	
Gravites from storage tank.	
65.	By Templer & Ranoe.
66. 3 ft. diam. 7 sq. ft. area.	
67. Horizontal surface.	Willans - Robinson, direct-coupled to turbo-exhaust by an expansion joint.
Mirrlees-Watson Co.	3, one for each unit; the top of condensers are 3ft. below water-level in cooling-tower.

[*Continued on p.* 577.

Name of Generating Station	Lots Road, Chelsea. [From p. 562.
Number and Position	8 in pits alongside each engine foundation.
Each condenses	
Height	Top within 29ft. of lowest tide.
Surface each	15,000 sq. ft.
Steam condensed per sq. ft. per hour at rated full load	7·7 lbs. with 20·9 lbs. (item 57, p. 532). 6·5 lbs. with 17·7 lbs.
Surface per lb. p. hr. of Steam,	0·13 (with 20·9 lbs. per K. W. H.).
Tubes: Number and Length	3822 tubes, 15ft. long, 1in. diam., set vertically.
Each Condenser has	3 motors, 40 horse-power, 40 horse-power, and 20 horse-power.
Steam passes through	Once 15ft. tubes.
Illustration	p. 559.
68. **Air Pumps**: Number	8.
Type	Worthington horizontal dry vacuum (separate lift pump).
Each Cylinder	24in. by 14in.
Discharge	
Each driven by	40 horse-power Westinghouse motor, 220 volts, 3 phase, 635 R.p.m.
Motor Spindle	Horizontal.
Discharge capacity	
Illustration	
69. **Lift Pumps**: Number	
Size	eight 5in. horizontal centrifugal for lifting condensed steam up to feed-pump suction.
Position of Pump	Bottom of condenser pit.
Each driven by	20 horse-power Westinghouse motor, 220 volts, 3 phase, 635 R.p.m.
Motor Spindle	Vertical.
Position of Motor	Basement level.
Water of Condensation to	
By Pump	
Driven by	

[Continued on p. 578.

[From p. 563.

	Neasden.	Carville.
	4, outside engine-room, wall directly opposite each turbine.	
	Overall height above ground, 47ft. [Condenses 66,500 lbs. per hour full load to 27in., and 110,000 lbs. per hour max. overload for 1 hour, vacuum 26in., max. overload guaranteed 90% of barometer.]	
	p. 472.	
68.	4.	3 (Fig. 355), p. 475.
	Two-stage tandem dry vacuum pump.	Parsons, three-throw.
	24in. diam., 24in. stroke.	
	To open air.	
	Steam engine direct.	3 phase motors.
	10in. diam. cylinder.	
69.		4 plunger pumps.
	4, Worthington.	Lift from air pump discharge to hotwell.
	Basement of engine-room.	On extension shaft of air pump.
	70 horse-power compound engine, 11in by 19in. by 11in., direct-coupled.	
	Hot-water type.	
	Centrifugal lift pump.	
	Westinghouse compound engine.	

[Continued on p. 579.

Name of Generating Station	**Delray, U.S.A.** [*From p.* 564.
Number and Position	4, one for each turbine in the basement in a room of 22ft. wide and 174ft. long, overhead travelling crane of 22ft. span and 15 tons capacity.
Each condenses	
Height	
Surface each	12,000 sq. ft. of tube cooling surface.
Steam condensed per sq. ft. per hour at rated full load	
Surface per lb. per hour	
Tubes: Number and Length	
Each Condenser has	
Steam passes through	
Illustration	p. 477.
68. **Air Pumps**: Number	4.
Type	Edward's wet vacuum triplex.
Each Cylinder	
Discharge	
Each driven by	50 horse-power, 220 volt, 3 phase motor.
Motor Spindle	
Discharge capacity	
Illustration	
69. **Lift Pumps**: Number	
Size	
Position of Pump	
Each driven by	
Motor Spindle	
Position of Motor	
Water of Condensation to	
By Pump	
Driven by	

[*Continued on p.* 580

L. Street Station, Boston, U.S.A.	Quincy Point, Mass., U.S.A. [*From p.* 565.
2 sub-base of turbine.	5.
153,000 lbs. per hour, with circulating water at 70° F. maintain vacuum 28in. of mercury; in winter it has maintained a vacuum within ⅞in. of barometer.	
20,000 sq. ft.	
7·6 lbs.	
0·13 sq. ft.	
1in. brass outside diameter and 18 gauge, 16ft. and 1⅜in. pitch centres.	
4 times.	
Figs. 388–390, pp. 545, 547.	p. 549.
68.	5.
Dry vacuum.	4 motor-driven Edward's triplex; 1 steam-driven Edward's triplex.
24in. by 18in. vertical air cylinder.	18in. by 12in.
10in. suction pipe, 8in. discharge pipe.	Into 3 tanks connected in series, each 20ft. long and 6ft. diam., located in boiler-room.
10in. by 18in. steam cylinder horizontal.	Four 50 horse-power General Electric induction motors, 350 volts, 3 phase.
	One 10in. by 10in. engine.
Figs. 388–390.	
69.	
"National" feed heater. 4in. volute, 1200 R.p.m. Motor.	Hotwell and storage tank consisting of 3 tanks in series in boiler-house, each tank 20ft. × 6ft. diam., from which boiler feed is taken.

[*Continued on p.* 581.

Name of Generating Station	Yoker. [*From p.* 566.
Number and Position	2 ; 1 alongside each turbine.
Each condenses	25,000 lbs. per hour. 50,000 lbs. total.
Height	
Surface each	6250 sq. ft. cooling surface.
Steam condensed per sq. foot per hour at rated full load	
Surface each per lb. of steam	
Tubes: Number and Length	14½ ft. long, 1 in. diam. 18 S.W.G.
Each Condenser has	
Steam passes through	Three lengths of tube.
Illustration	"Counter" to steam, p. 550.
68. **Air Pumps**: Number	2 in Basement.
Type	Two-stage dry air pump horizontal. Both air cylinders fitted with mechanically controlled slide.
Each Cylinder	
Discharge	
Each driven by	Steam.
Motor Spindle	
Discharge capacity	
Illustration	
69. **Lift Pumps**: Number	
Size	
Position of Pump	
Each driven by	
Motor Spindle	
Position of Motor	
Water of Condensation to	Hotwell in the basement.
By Pump	Centrifugal pump.
Driven by	6 horse-power vertical-shaft shunt-wound motor, 625 R.p.m.

[*Continued on p.* 582.

Motherwell.	**Thornhill.** [*From p.* 567.
	4 ; one alongside each turbine.
80,000 lbs. per hour to 27·5 ins. vacuum, using 44 lbs. of water at 80° F. per 1 lb. steam. *Engineer*, 23/6/05.	
	16ft.
	4500 sq. ft.
	18 S.W.G. brass ¾in. diam.
	4 lengths of tube.
p. 561.	Fig. 397, page 553.
68. Two Alberger Corliss two-stage dry vacuum pumps.	4, one to each condenser. Three-throw, Edward's.
	15in. diam., 8in. stroke.
	6in. diam. into hotwell.
	15 horse-power motor, 185 R.p.m. full load, 240 R.p.m. no load, 220 volts compound.
	24,000 cub. ft. per hour.
69.	

[*Continued on p.* 583.

[*From p.* 568.

Name of Generating Station	**Radcliffe.**
Number and Position	
Each condensers	
Height	
Surface each	4500 sq. ft.
Steam condensed per sq. ft. per hour at rated full load	5·4.
Surface per lb. per hour	0·18 (with 16·4 lbs. per K.W.H.).
Tubes: Number and Length	
Each Condenser has	
Steam passes through	
Illustration	p. 555.
68. **Air Pumps**: Number	4, one to each condenser.
Type	Edward's three-throw.
Each Cylinder	15in. diam., 8in. stroke.
Discharge	
Each driven by	Motor, 165 R.p.m.
Motor Spindle	
Discharge capacity	24,000 cub. ft. per hour.
Illustration	
69. **Lift Pumps**: Number	
Size	
Position of Pump	
Each driven by	
Motor Spindle	
Position of Motor	
Water of Condensation to	
By Pump	
Driven by	

[*Continued on p.* 584.

	Brimsdown.	Power Station of the English M'Kenna Process Co., Ltd. [*From p.* 569.
	Three, alongside each turbo.	3.
	6 ft. 9 in.	
	2400 sq.. ft	2530 sq. ft.
	7.	
	About 10 ft. 4 in. long.	
	p. 557.	pp. 488, 489.
68.	3.	
	Edward's three-throw.	Edward's two-throw type, with a force pump (delivering to hotwell) driven from the end of crank shaft, drawing from the surge tank at base of air pump, into which the air pump itself delivers.
	12½in. diam. 6in. stroke.	
	Motor 9 horse-power, 110 volts c.c.	9½ horse-power Siemens shunt motor 250 volts, 750 to 850 R.p.m., 17 amp., with 27½ in. vacuum.
	2500 gallons per hour.	
69.		A 150 K.W. rotary and a 50 K.W. rotary, and transformers off main bus-bars supply 250 volt current for driving condenser plant.

[*Continued on p.* 585.

Name of Generating Station	Lots Road, Chelsea. [From p. 570.
70. Circulating Pump	
Maker	Worthington.
Number	8, piped on syphon principle.
Type	20in. centrifugal horizontal.
Position	Bottom of condenser pit.
Each driven by	40 horse-power motor, Westinghouse, 220 volts, 3 phase, 635 R.p.m.
Motor Spindle	Vertical spindle.
Position of Motor	At basement level.
Rated Duty	
Circulating Water from	River Thames.
Intake Pipe	66in. diam. cast-iron in river bed.
Discharge Pipe	,, ,, ,,
Direction of Flow	Reversible up to condenser.
Pipes supplied and laid by	John Cochrane & Sons, Westminster.
Circulation Pipes	Steel riveted to get hold of concrete on land.
Pipes supplied by	Babcock & Wilcox.
Pipes laid by	Perry.
Circulating Pipes to Condensers	20in. and 22in. diameter of cast-iron.
Circulation provided for is	times steam consumption.
70A. Cooling Towers: Number	
Capacity per hour	
Area each	
Height	
Space between	
Area Tank under towers	
Depth ,, ,,	
Distributing Pipes	
71. Main Generators	Figs. 383, 384, *ante*, also pp. 140/4.
Number	8, with room for 10, and 1 half-size.
Maker	Westinghouse.
Rating	5500 K.W.
Number of Phases	3.
Cycles per second	$33\frac{1}{3}$.
Speed	1000 R.p.m.
Voltage per phase	11,000.
Amperes per phase, full load	289, with non-inductive load.
Temperature rise	
Regulation	
Speed variation	
Overload	50 per cent. for two hours.
Temperature rise	

[Continued on p. 586.

Neasden.	Carville. [*From p.* 571.
70. *Injection pump.*	
Gwynn & Co.	
4.	2.
	Centrifugal.
Basement of engine-room.	
18in. by 10in. Westinghouse compound engine, direct-coupled.	3 phase motor.
60 horse-power.	Each sufficient for 2 sets.
Tank at base of towers.	River Tyne.
20in. diam. from culvert; 18in. diam. intake.	
Westinghouse & Co.	
70A. 6 Duplex Zschocke by T. Sugden, Ltd.	
1,600,000 gallons per hour total.	
2800 sq. ft. net, 111ft. by 25ft.	
78ft. above ground-level.	
12ft. 6in. See Fig. 404, *ante.*	
220ft. by 114ft. = 25,000 sq. ft.	
3ft. 3in.	
25ft. above ground, 40ft. of 28in. diam., 300ft. of 20in. diam., 100ft. of 17in. diam., 100ft. of 14in. diam., 150ft. of 10in.	
71. Fig. 385, *ante.*	Fig. 355, *ante*, p. 475.
4.	4.
British Westinghouse.	Parsons.
3500 K.W.	3500 K.W. (or 4000) also 2000 K.W.
3.	3.
33½.	40.
1000 R.p.m	
11,000.	5750. (?) 6000.
2½ per cent. variation by resistance in exciting circuit; 184 non-inductive load.	
40° C.	
2½ per cent.	
25 per cent. for 6 hours.	See item 56, p. 533.
Under 50° C.	

[*Continued on p.* 587.

Name of Generating Station .	**Delray, U.S.A.** [*From p.* 572.
70. Circulating Pump . . .	**In the pump-house, 33ft. by 87ft.**
Maker	**Worthington.**
Number	**4.**
Type	**18in. centrifugal.**
Position	**Main floor of pump-house.**
Each driven by . . .	**75 horse-power induction motor.**
Motor Spindle . . .	
Position of Motor . .	
Rated Duty . . .	
Circulating Water from .	Detroit River.
Intake Pipe . . .	3 sets of screens to stop rubbish, first, vertical bars; others removable wire nets.
Discharge Pipe . . .	A culvert extending beneath the four condensers.
Direction of Flow . .	
Pipes supplied and laid by .	
Circulation Pipes . .	
Pipes supplied by . .	
Pipes laid by . . .	
Circulating Pipes to Condensers	
Circulation provided for is .	
70A. Cooling Towers: Number .	
Capacity per hour . .	
Area each	
Height	
Space between . . .	
Area Tank under towers .	
Depth ,, ,, .	
Distributing Pipes . .	
71. Main Generators . . .	Fig. 386, *ante*, p. 543.
Number	4.
Maker	Gen. Elec. Co. of New York.
Rating	3000 K.W.
Number of Phases . .	3.
Cycles per second . .	60.
Speed	600 R.p.m.
Voltage per phase . .	4600.
Amperes per phase, full load	
Temperature rise . .	
Regulation . . .	
Speed variation . . .	
Overload	50 per cent. continuously without damage; 70 per cent. for a short time.
Temperature rise . . .	

[*Continued on p.* 588.

L. Street Station, Boston, U.S.A.	Quincy Point, Mass., U.S.A. [*From p.* 573.
70.	
	5.
24in. volute centrifugal for priming an ejector on discharge.	4 motor-driven, 1 steam-driven, 18in. low-lift double-suction Morris type.
15in. by 15in. Harrisburg engine, 200 R.p.m.	Four 100 horse-power G.E. induction motor, 350 volts; one 12in. by 10in. steam engine.
2 masonry conduits 56 sq. ft. each.	
2 fine copper screens in series, cleaned by removing one.	
1 masonry conduit 78 sq. ft., discharge kept from intake by Wing-dam.	
2 opening through sea wall, each 5½ by 13ft. with submerged racks.	
70 times steam consumption.	
70A.	
71. Figs. 388, 389, 390, *ante*, p. 545.	Figs. 391, 392, 393, *ante*, p. 549.
2.	5.
Gen. Elec. Co. of New York.	Gen. Elec. Co. of New York.
5000 K.W.	2000 K.W.
3.	3.
60.	25.
514 R.p.m.	750 R.p.m.
	13,200.
50 per cent. for 2 hours.	

[*Continued on p.* 589.

Name of Generating Station	**Yoker.** [*From p.* 574.
70. **Circulating Pump**	
Maker	
Number	
Type	Centrifugal.
Position	
Each driven by	Steam-driven.
Motor Spindle	
Position of Motor	
Rated Duty	
Circulating Water from	River Clyde alongside, by gravity into well, 18ft. diam. and 9ft. below low-water level, by 2 pipes, each 30in. diam.
Intake Pipe	36in. diam. cast-iron.
Discharge Pipe	36in. diam. into spillway on bank of river.
Direction of Flow	
Pipes supplied and laid by	
Circulation Pipes	
Pipes supplied by	
Pipes laid by	
Circulating Pipes to Condensers	
Circulation provided for is	
70A. **Cooling Towers**: Number	
Capacity per hour	
Area each	
Height	
Space between	
Area Tank under Towers	
Depth ,, ,,	
Distributing Pipes	
71. **Main Generators**	Figs. 394/6, p. 550, also pp. 146/7.
Number	2.
Maker	Westinghouse.
Rating	2000 K.W.
Number of Phases	3.
Cycles per second	25.
Speed	1500 R.p.m.
Voltage per phase	11,000.
Amperes per phase, full load	
Temperature rise	
Regulation	
Speed variation	
Overload	50%.
Temperature rise	

[*Continued on p.* 590.

Motherwell.

70.

The station being 400 yds. from & 140 ft. above the river there is installed

70A. A Balcke Tower
220,000 gals. per hour from 120° F. to 80° F. (air 70° F.).

73 ft.

Evaporation 2½ per cent.

71. Duplicate of Yoker.

Thornhill. [*From p.* 575.

4.
Gwynne Centrifugal.

Basement.
43 horse-power at 645 R.p.m., varied by shunt control to 54 horse-power at 845 R.p.m., 220 volts shunt-wound.

160,000 gals. per hour against 28ft. head.

River Calder alongside.

12ins. diam. to each.

18ins. diam. for all.

63 times weight of steam at rated load.

Fig. 397/8, *ante*, p. 553.
4.
British Thomson-Houston Co., Ltd., of Rugby.
1500 K.W., with 85 per cent. power factor.
3.
50 cycles per second.
1000 R.p.m.
11,000 volts generated.
93½.

40° C. after 24 hours.
8 per cent. variation in volts when full load is thrown off.
4 per cent. under sudden changes.
50 per cent. 2 hours.

60° C. 2 hours.

[*Continued on p.* 591,

Name of Generating Station	Radcliffe.
70. **Circulating Pump**	
Maker	
Number	
Type	
Position	
Each driven by	
Motor Spindle	
Position of Motor	
Rated Duty	
Circulating Water from	
Intake Pipe	
Discharge Pipe	
Direction of Flow	
Pipes supplied and laid by	
Circulation Pipes	
Pipes supplied by	
Pipes laid by	
Circulating Pipes to Condensers	
Circulation provided for is	
70A. **Cooling Towers**: Number	
Capacity per hour	
Area each	
Height	
Space between	
Area Tank under Towers	
Depth ,, ,,	
Distributing Pipes	
71. **Main Generators**	Fig. 399/400, *ante*, p. 555.
Number	
Maker	
Rating	
Number of Phases	
Cycles per second	
Speed	
Voltage per phase	
Amperes per phase, full load	
Temperature rise	
Regulation	
Speed variation	
Overload	
Temperature rise	

[*From p.* 576.

[*Continued on p.* 592.

Brimsdown.	**Power Station of the English M'Kenna Process Co., Ltd.** [*From p.* 577.
70. Centrifugal.	
Gwynne.	Allen.
	1.
At side of condenser.	
Motor, direct-coupled.	45 B.H.P. Siemens shunt motor, direct current, 250 volts, 605 to 705 R.p.m., the current taken, 110 amps. at 250 volts, maintaining a steady vacuum of 27½in. at full load.
1700 gallons per minute.	100,000 gallons per hour, against 27ft. head to Donat cooling tower.
Lea Canal.	By gravity through condenser to suction side of circulating pump.
In suction pits.	10in. diam.
Into coal barge dock.	
J. Spencer & Co.	
10-in. diam. to each.	
60 times full-load steam.	1 Donat, 2700 sq. ft.
70A. No towers.	
71. Fig. 401, p. 557.	Fig. 368/370, *ante*, p. 488.
3.	3.
Brown-Boveri.	
1000 K.W.	750 K.W. at 0·8 power factor.
3.	3.
50.	25.
1500 R.p.m.	1500 R.p.m.
10,000.	440.
68 amps.	
8 per cent.	
25 per cent. for 1 hour.	
Test: 25° C. after 6 hours' full load.	

[*Continued on p.* 593.

Name of Generating Station	Lots Road, Chelsea. [From p. 578.
Rotor	Solid Whitworth fluid-pressed steel.
Number of Poles	4.
Excitation	125 volts, 180 amps. full load.
Per cent. of Output	0·4 per cent. unity power factor.
Electrical Efficiency	
1¼ load	
Full load	97¼ per cent.
¾ load	96½ per cent.
½ ,,	95 per cent.
¼ ,,	90 per cent.
Dimensions	
72. Exciters, take steam through	
Exhaust into	
Engines : Number	4.
Horse-power	200 horse-power.
Maker	W. H. Allen, Son & Co., Ltd., Bedford.
Overload	25 per cent.
Type	Compound enclosed.
Cylinder diameters	12in. and 21in.
Stroke	9in.
Speed	375 R.p.m.
Lubrication	Forced.
,, Pressure	
Consumption guaranteed	
,, with Pressure	165 lbs. per sq. in. pressure.
,, ,, Superheat	23° F. superheat.
,, ,, Vacuum	24ins. vacuum.
Full Load condensing	15·7 lbs. of steam per I.H.P. hour, equal to 25·4 lbs. of steam per K.W. hour.
Half ,, ,,	
Full Load non-condensing	
Half ,, ,,	
Exciter Generator	
Number	4 direct-coupled.
Maker	British Thomson-Houston Co., Ltd.
Rating	125 kilowatts.
Percentage of total Kilowatts installed	1·1 per cent.
Voltage	125 volts.
Type	6 pole, flat compound.
Overload capacity	25 per cent. for 2 hours without moving brushes; 50 per cent. momentarily.
Temperature rise	
Electrical Efficiency	
Full load	
Half load	

[Continued on p. 594.

Neasden.

Ironclad type weighing 17 tons.
4.
125 volts.

97·4 per cent.;[1]
96½ per cent.[2]; 97 per cent.;
95½ per cent.; 96 per cent.;
93¾ per cent.; 94·5 per cent.

39ft. long by 11ft. wide (ex platform), 10ft. high, generator circle 10ft. diam.
72. 8in. auxiliary pipe from 12in. header.
700 sq. ft. Alberger surface condenser.

2.

Westinghouse.
50 per cent.
Single-acting compound engine.
13in. and 22in.

13in.
275 R.p.m.

Oil bath.

2.

Westinghouse.
100 kilowatts.

1·4 per cent.

125.

Compound wound.

50 per cent.

Carville. [From p. 579.

100 volts.

[Continued on p. 595.

[1] *Engineer*, Feb. 26, 1904, p. 202.

[2] *Science Abstracts*, No. 2330, p. 897.

Name of Generating Station	Delray, U.S.A. [*From p.* 580.
Rotor	
Number of Poles	12.
Excitation	
Per cent. of Output	
Electrical Efficiency	
$1\frac{1}{4}$ load	
Full load	
$\frac{3}{4}$ load	
$\frac{1}{2}$,,	
$\frac{1}{4}$,,	
Dimensions	
72. **Exciters**, take steam through	
Exhaust into	
Engines : Number	1 engine-driven exciter for emergency use in basement.
Horse-power	
Maker	
Overload	
Type	
Cylinder diameters	
Stroke	
Speed	
Lubrication	
,, Pressure	
Consumption guaranteed	
,, with Pressure	
,, ,, Superheat	
,, ,, Vacuum	
Full Load condensing	
Half ,, ,,	
Full Load non-condensing	
Half ,, ,,	
Exciter Generator	
Number	3; also a storage battery of 83 cells, at 125 volts and capacity 400 amp.-hours for three consecutive hours.
Maker	
Rating	50 kilowatts.
Percentage of total Kilowatts installed	1·2 per cent.
Voltage	125 to 200 volts.
Type	Motor generators driven by 75 horse-power induction motors.
Overload capacity	
Temperature rise	
Electrical Efficiency	
Full load	
Half load	

[*Continued on p.* 596.

L. Street Station, Boston, U.S.A.	**Quincy Point, Mass., U.S.A.** [*From p.* 581.
28 K.W. 0·56 per cent.	
72.	
3.	2; one 75 K.W. and 50 K.W.
	General Elec. Co., Schenectady.
	Vertical comp.
	310 R.p.m. 75 K.W. engine. 400 ,, 50 ,,
	3, one being a 50 kilowatt motor generator (350 volts 75 horse-power 3 phase motor). General Elec. Co., Schenectady. 75 kilowatts, 50 kilowatts, and 50 kilowatts. 1·75 per cent.

[*Continued on p.* 597

[From p 582.

Name of Generating Station	Yoker.
Rotor	
Number of Poles	
Excitation	
Per cent. of Output	
Electrical Efficiency	
1¼ load	
Full load	
¾ load	
½ ,,	
¼ ,,	
Dimensions	
72. **Exciters**, take steam through	
Exhaust into	A separate Worthington surface condenser, 600 sq. ft. cooling surface.
Engines : Number	2.
Horse-power	Each 75 K.W.
Maker	Westinghouse. Fig. 396, p. 552.
Overload	
Type	Vertical compound.
Cylinder diameters	11in. and 19in. diam.
Stroke	11in.
Speed	290 R.p.m.
Lubrication	
,, Pressure	
Consumption guaranteed	
,, with Pressure	
,, ,, Superheat	
,, ,, Vacuum	
Full Load condensing	
Half ,, ,,	
Full Load non-condensing	
Half ,, ,,	
Exciter Generator	
Number	2.
Maker	
Rating	
Percentage of total Kilowatts installed	
Voltage	125 volts d. c. (supply also coal and ash conveyer, crushers, agitators, economisers, pumps, travelling crane switches).
Type	Compound.
Overload capacity	
Temperature rise	
Electrical Efficiency	
Full load	
Half load	

[Continued on p. 598.

Motherwell.	**Thornhill.** [*From p.* 583.
	6.
	17ft. 8in. high, turbo-generator, set 10ft. diameter.
72. Duplicate of Yoker.	3¾in. diam. branch (off 6in.). 6½in. ,, to feed water heater.
	3.
	Each 220 horse-power at full load. Allen, B.T.H. Fig. 398, p. 554.
	Recip. comp., non-condensing.
	12in. and 21in. 9in. 420 R.p.m.
	Automatic forced. 15 lbs. per sq. in.
	160 lbs. pressure. 100° F. superheat. 26in. vacuum. 24·8 lbs. per I.H.P.
	28·7 ,, 30·7 ,, 41·7 ,,
	Three 6 poles.
	British Thomson-Houston Co., Ltd 150 kilowatts.
	10 per cent.
	220 volts.
	Compound.
	25 per cent. for 2 hours.
	40° C. after 24 hours at full load, any part except 50° C. after 24 hours on commutator.
	92 per cent. 90 per cent.

[*Continued on p.* 599.

[From p. 584.

Name of Generating Station	Radcliffe.
Rotor	
Number of Poles	
Excitation	
Per cent. of Output	
Electrical Efficiency	
$1\frac{1}{4}$ load	
Full load	
$\frac{3}{4}$ load	
$\frac{1}{2}$,,	
$\frac{1}{4}$,,	
Dimensions	
72. Exciters, take steam through	
Exhaust into	Feed-water heater.
Engines: Number	
Horse-power	3 sets of Allen engines also as auxiliary power.
Maker	Allen & B.T.H. Co.
Overload	
Type	
Cylinder diameters	
Stroke	
Speed	
Lubrication	
,, Pressure	
Consumption guaranteed	
,, with Pressure	
,, ,, Superheat	
,, ,, Vacuum	
Full Load condensing	
Half ,, ,,	
Full Load non-condensing	
Half ,, ,,	
Exciter Generator	
Number	Three 6 poles.
Maker	British Thomson-Houston Co., Ltd.
Rating	150 kilowatts.
Percentage of Total Kilowatts installed	7·5 per cent.
Voltage	220 volts.
Type	Compound.
Overload capacity	
Temperature rise	
Electrical Efficiency	
Full load	
Half load	

[Continued on p. 600.

Brimsdown.	Power Station of the English M'Kenna Process Co., Ltd. [*From p.* 585.
Guarantee 40° C. after 10 hrs. full load.	
4.	2.
80 amps., 110 volts. (p.f. = 1).	250 volts originally, 65 volts now.
95 per cent. (p.f. = 1).	
94 per cent.	
92 per cent.	
12ft. 8in. × 6ft. 7in. × 6ft. 6in. high.	
72.	
2 condensers (2 engines to each).	
Four.	2. Originally for exciting, etc.
2 of 150 B.H.P. | 2 of 80 B.H.P.	
Belliss-B.T.H. sets.	Belliss.
None.	
Compound 2 crank.	Bellis-Siemens type.
9 and 15in. | 7½ and 12in.	These also do lighting. These are now superseded for exciting current by 65 volt sets.
9 in. | 6 in.	
435 R.p.m. | 575 R.p.m.	
Forced.	
30 lbs. per sq. in.	
150 lbs. per sq. in.	
16 lbs. per hr. | 17¾ lbs. per hr.	
Four.	2. Direct-driven exciter *now* off generator shaft.
B.T.H. Co.	
2 of 100 K.W. | 2 of 50 K.W.	
10 per cent.	
110 volts.	65 volts now.
	Siemens.
75° F. after 24 hrs. at full load.	
91 per cent. | 90½ per cent.	
87 per cent. | 87 per cent.	

[*Continued on p.* 601.

Name of Generating Station	Lots Road, Chelsea. [From p. 586.
73. Overhead Travelling Cranes: Number	2.
Size	
Type	
Maker	Herbert, Morris & Bastert.
Capacity	20 tons each.
Span	57ft.
Lifting: Height	57ft.
Motive Power	125 volts continuous current.
Number of Motors	
Maker	
Lifting Motor Horse-power Speed	
Cross-run Horse-power Speed	
Long-run Horse power Speed	
74. Switchgear, made by	B.T.H. Co. Diagrams, Figs., pp. 602, 605.
High-tension Switches	Oil.
,, operated by	c.c. motors, 220 volts.
Generator Switches	First gallery. Figs. 407, 408, 409.
Bus Junction ,,	Second ,, Fig. 413.
Bus-bars	Separate compartments.
Feeder Switches	Third gallery.
Generator Instrument Panels	11 panels vertical. Fig. 412, p. 607.
Position	Second gallery, on projecting gallery, overlooking turbo-generators.
On each	3 A.C. ammeters; voltmeter; indicating wattmeter; recording wattmeter; power factor meter; field ammeter.
Generator Control Panels	11 on table beneath instrument panels.
On each	Generator oil switch; bus junction switch; feeder group switch; indicating lamps; field rheostat controller; field discharge switch; governor control switch, engine signal; synchronising switch.
Feeder Inst. & Control Board	Fig. 410.
Number of Feeder Panels	17.
Oil Switch Motor Control Panel	1 c.c. 220 volts.
Number of Feeders	68.
Each Feeder has	Ammeter; wattmeter; control switch; indicating lamps—red, closed; green, open switch. Overload time-limit relays, with electric gong to sound when feeder switch opens.
Auxiliary Switchboard Controls	Four 125 K.W. exciter, 220 volts; 3 sets of 3 transformers; one 125 K.W. synchronous motor generator; 2 batteries of accumulators; 89 motors, 3 ph. 220 volts; 12 motors c.c., 125 volts; 93 oil switch motors, 220 volts; local lighting. Figs. 415, 416.
Panels	2 battery panels; 2 c.c. feeder panels; 2 motor generator panels; 1 load panel; 4 exciter (single pole) panels; 13 a.c. panels; hand operated oil switches.
Position	First end gallery.
Exciter Bus	In 2 sections.
A. C. Bus, 220 volts	Under floor in 2 sections.
Emergency Switches	Throw oil switch motors on to motor generator, or one exciter if batteries fail.
Generator Cables	In screwed piping imbedded in concrete gallery floor with no junction boxes.

[Continued on p. 626

Neasden.	**Carville.** [*From p.* 587.
73. 2.	
Higginbottom & Mannock.	Messrs Craven Bros.
20 tons each.	40 tons and one auxiliary crab of 10 tons.
46ft.	63ft.
30ft.	40ft.
125 volts direct curt. off exciter circuit.	3 phase induction motor by B.T.H. Co.
3.	1 for main crab, 1 for auxiliary crab.
10 horse-power, *30ft. per min.*	4 ft. per min. main, 25ft. per min. auxiliary.
5 horse-power, *50ft. per min.*	
5 horse-power, *110 ft. per min.*	
74. Westinghouse.	B.T.H. Co. Diagram, Fig. 417, p. 611.
	Oil.
Magnetic control from master board.	Motors.
Diagram of connections mounted on marble board.	Figs. 418–421, 425–427, p. 612.
Switches in this diagram are operated by the actual switches, thus operator has before him a correct diagram of connections existing at every moment.	Diagram synchronising connections, Fig. 423. Control board: 3 enamelled slates. Generator panel in middle. Feeder panel for N.E.R. Co. on left hand. Feeder panel for other consumers on right. Swinging panels carry bus voltmeters, rotary synchroniser, synchronising lamps and voltmeters.
	Fig. 419, p. 612.
Similar to Fig. 429, Yoker, p. 618.	Switchboard on 5 galleries 10ft. high. Lowest gallery; leading in cables. Second (turbine floor level): instrument transformers. Third: main switches; control board. Fourth: 3 bus-bars, each 2·5 sq. in. Fifth: 3 bus-bars, each 2·5 sq. in. The only connections to bus-bars are the main cables. All small wiring is on machine or feeder side of switch respectively.
	Diagram, Fig. 424, p. 613.
	3 separate cables from generators to switchboard. (3 core feeder cables to substations).

[*Continued on p.* 627.

Name of Generating Station .	**Delray, U.S.A.**	[*From p.* 588.
73. Overhead Travelling Cranes:		
Number		
Size	1 electric.	
Type		
Maker	Northern Engineering Co.	
Capacity	35 tons.	
Span	51ft.	
Lifting: Height . .		
Motive Power . . .	3-phase induction motors.	
Number of Motors . .		
Maker		
Lifting Motor Horse-power Speed		
Cross-run Horse-power Speed		
Long-run Horse-power Speed		
74. Switchgear, made by . .		
High-tension Switches .	Fig. 428, p. 617.	
,, operated by .	125 volt exciting circuit.	
Generator Switches . .	First gallery.	
Bus Junction ,, . .		
Bus-bars	Below first gallery.	
Feeder Switches . . .		
Generator Instrument Panels		
Position	Second gallery.	
On each		
Generator Control Panels .	24 panels.	
On each		
Feeder Inst. & Control Board		
Number of Feeder Panels	9.	
Oil Switch Motor Control Panel		
Number of Feeders .		
Each Feeder has . .		
Auxiliary Switchboard Controls		
	Rheostats worked by sprocket chains run in iron pipes.	
Panels		
Position		
Exciter Bus . . .		
A. C. Bus, 220 volts .		
Emergency Switches .		
Generator Cables . .		

[*Delray ends.*

L. Street Station, Boston, U.S.A.

73.

74.

[*L. Street, Boston, ends.*

Quincy Point, Mass., U.S.A.

[*From p.* 589.

3 series-wound, totally enclosed.
Westinghouse.
25 horse-power, 460 R.p.m.

4 horse-power, 935 R.p.m.
10 horse-power, 650 R.p.m.

Fig. 429.
Low voltage auxiliary circuit.

In cells on switchboard floor.

5.

Three 13,200 volts feeder panels.

1 c.c. booster panel; 1 totalising panel; 3 a.c. and 3 c.c. rotary panels; 4 c.c. feeder panels; 1 emergency feeder panel; 3 exciter panels; 2 auxiliary panels.
(1 substation is in gallery in main turbine room.)

[*Continued on p.* 629.

Name of Generating Station .	Yoker. [From p. 590.
73. **Overhead Travelling Cranes:**	
Number . . .	
Size	1.
Type	3 motors.
Maker . . .	C. A. Musker & Co.
Capacity	30 tons.
Span	42ft.
Lifting: Height . .	125 volts from exciters.
Motive Power . . .	
Number of Motors . .	
Maker	
Lifting Motor Horse-power Speed	25 horse-power, 460 R.p.m. series.
Cross-run Horse-power Speed	4 horse-power, 935 R.p.m. series.
Long-run Horse-power Speed	10 horse-power, 650 R.p.m. series.
74. **Switchgear,** made by . .	Westinghouse, in 3 galleries.
High-tension Switches .	Figs. 430, 431, 432.
,, operated by .	Exciter circuit.
Generator Switches . .	
Bus Junction ,, . .	
Bus bars	Top gallery in brick compartments.
Feeder Switches . . .	
Generator Instrument Panels	
Position	
On each	
Generator Control Panels .	See Fig. 429, p. 618.
On each	Diagram as described under Neasden, p. 595
Feeder Inst. & Control Board	
Number of Feeder Panels	
Oil Switch Motor Control Panel	
Number of Feeders .	
Each Feeder has . .	
Auxiliary Switchboard Controls	
Panels	
Position . . .	
Exciter Bus . . .	
A. C. Bus, 220 volts .	
Emergency Switches .	
Generator Cables . .	

[*Yoker ends.*

Motherwell.

73.

74. Westinghouse.

Duplicate of Yoker.

[Motherwell ends.

Thornhill. *[From p.* 591.

25 tons.
33ft.
40ft.

B.T.H Co.
Oil. Figs. 433, 434, p. 621.
c.c. motors, 220 volts, on 3 floors in separate building, opening to engine-room.

4.

1 panel controls section switch, and synchronising.

3 exciters, 220 volts, 150 K.W. auxiliary.

3 exciter panels, 4 auxiliary motors, and lighting single pole (16 circuits).

Earth cable to all plant.

[Thornhill ends.

Name of Generating Station	**Radcliffe.** [*From p.* **592.**
73. Overhead Travelling Cranes:	
Number	
Size	
Type	
Maker	
Capacity	
Span	
Lifting: Height	
Motive Power	
Number of Motors	
Maker	
Lifting Motor Horse-power Speed	
Cross-run Horse-power Speed	
Long-run Horse-power Speed	
74. Switchgear, made by	B.T.H. Co. **Diagram, Fig. 435, p. 622.**
High Tension Switches	Oil.
,, operated by	c c. motors.
Generator Switches	**Fig. 436, p. 623.**
Bus Junction ,,	
Bus-bars	
Feeder Switches	
Generator Instrument Panels	4 generator oil switches.
Position	Control switches and instruments mounted together.
On each	
Generator Control Panels	
On each	
Feeder Inst. & Control Board	
Number of Feeder Panels	10 feeder oil switches.
Oil Switch Motor Control Panel	
Number of Feeders	
Each Feeder has	
Auxiliary Switchboard Controls	Fig. 437, p. 624.
Panels	
Position	
Exciter Bus	
A. C. Bus, 220 Volts	
Emergency Switches	
Generator Cables	

[*Radcliffe ends.*

Brimsdown.

78. One.

Carrick and Ritchie.
25 tons.
45 ft.
19.
Electric.
One of 10 horse-power.

18in. per min. full load up to 10 ft. per min. light load.
40ft. per min.
40ft. per min.
B.T.H. Co.
Oil.
c.c. motors.

The data on Brimsdown was supplied by Mr A. H. Pott, chief engineer.

[Brimsdown ends.

Power Station of the English M'Kenna Process Co., Ltd. [*From p.* 593.

47ft.
30ft.
Hand.

Siemens. Fig. 437A, p. 625.

3 generator panels.
1 load panel.

1 a.c. and 1 c.c. rotary panels; one lighting panel; 2 exciter panels; 6 feeder panels. The load is 6 sets of rolls, driven by six 500 horse-power 3 ph. induction motors, with pilot control gear.

To stop the rolls the automatic circuit breaker is tripped by a push-button circuit, which also starts a pilot motor on starting switch, thus cutting in resistance ready for a fresh start, and during this operation a pilot lamp glows.
To start, another bell circuit signals which circuit breaker is to be closed. As soon as the pilot motor has cut out all resistance attendant signals "commence rolling."

[English M'Kenna Plant ends.

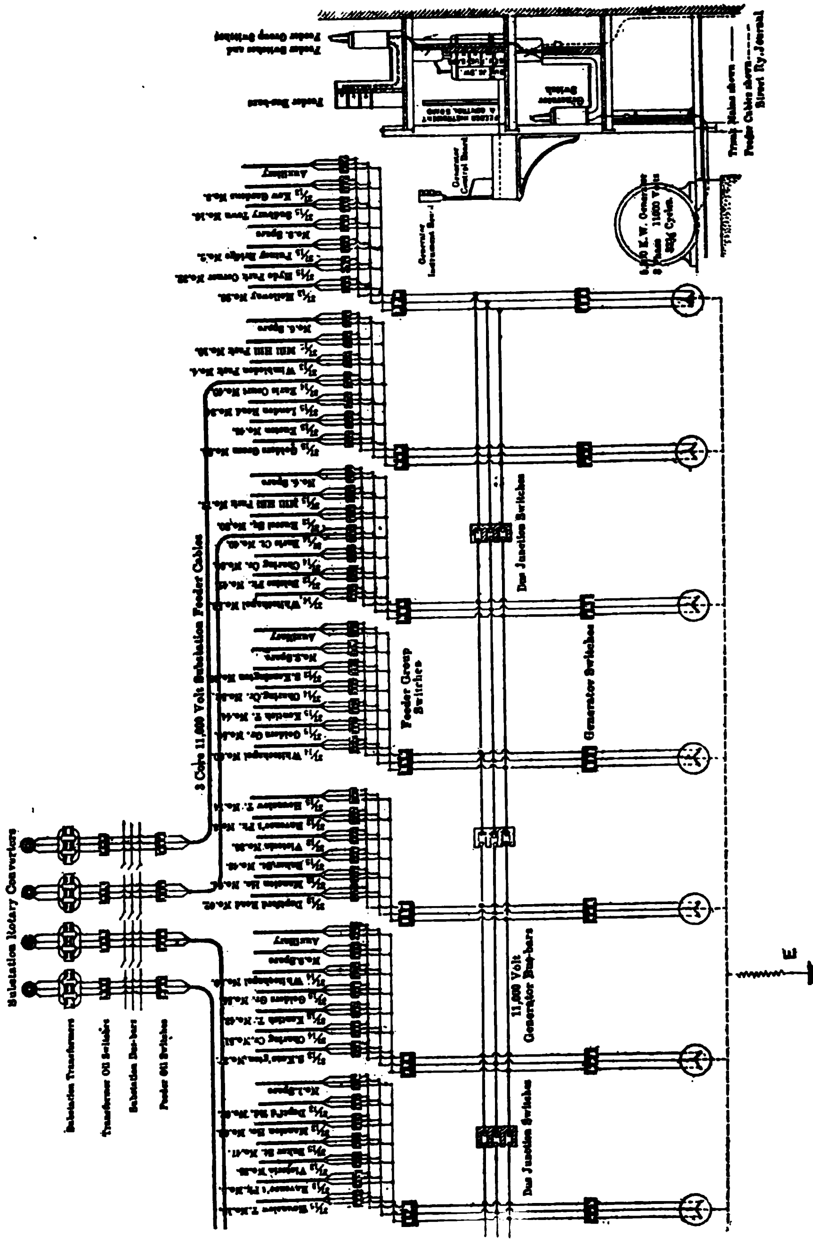


FIG. 406.—Lots Road, Chelsea: Diagram of 11,000 Volt Circuits.

Seven Generators are shown. There are to be added three 5500 K.W. and one 2750 K.W. Sets.

(By permission of Mr S. B. Fortenbaugh and "Street Railway Journal.")

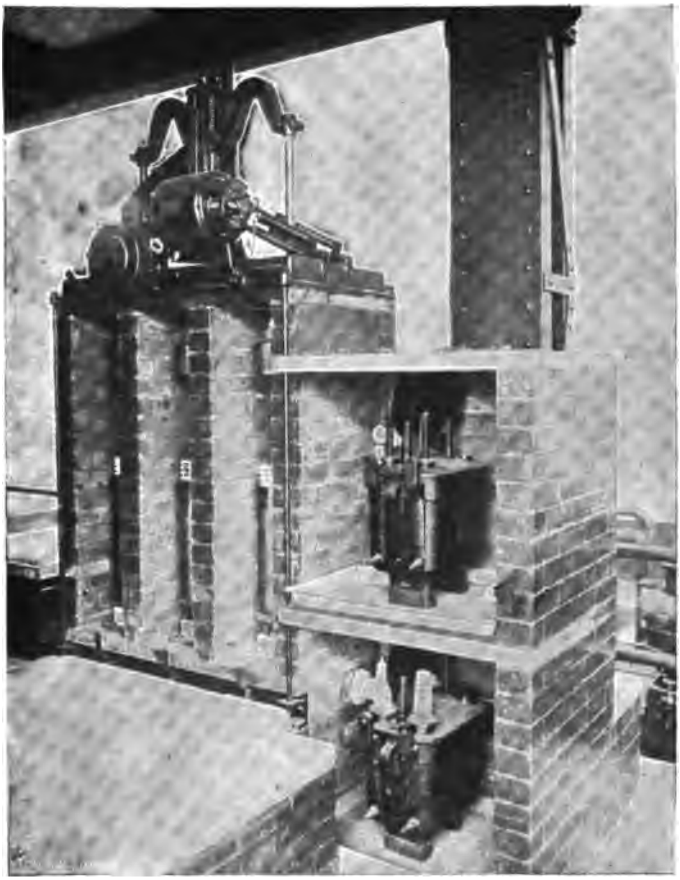


FIG. 407.—Lots Road, Chelsea: Generator Switch and Potential Transformers.

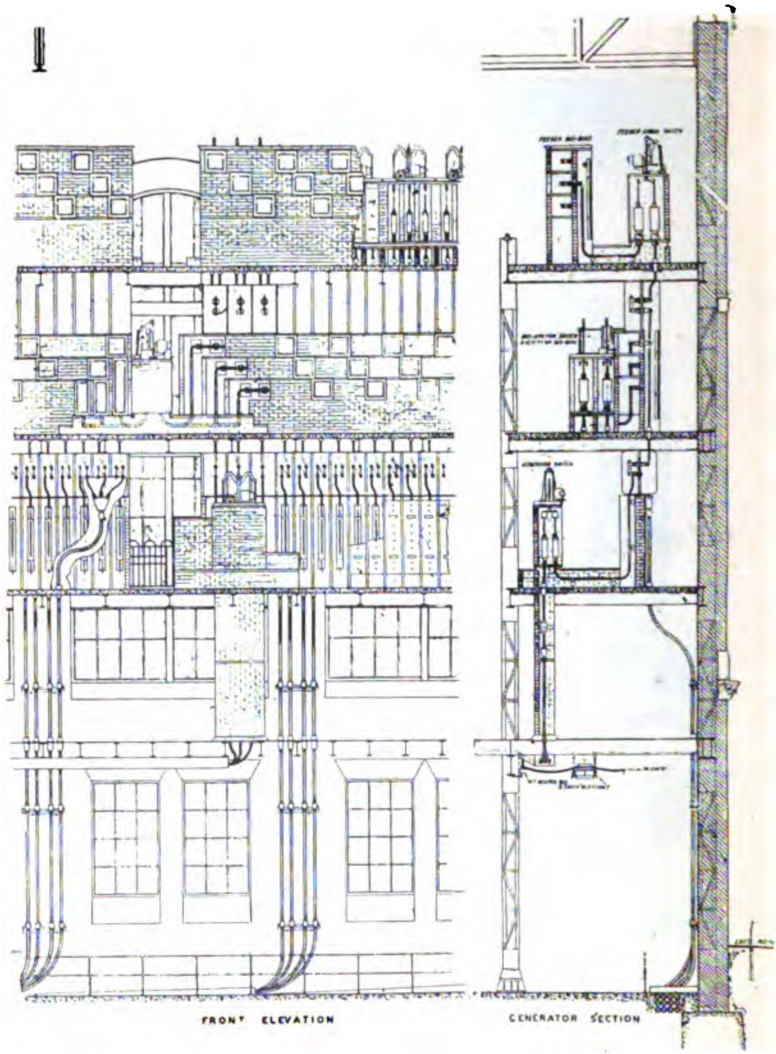


FIG. 408.

FIGS. 408, 409, and 410.—Lots Road, Chelsea : Front and Side Elevations of parts

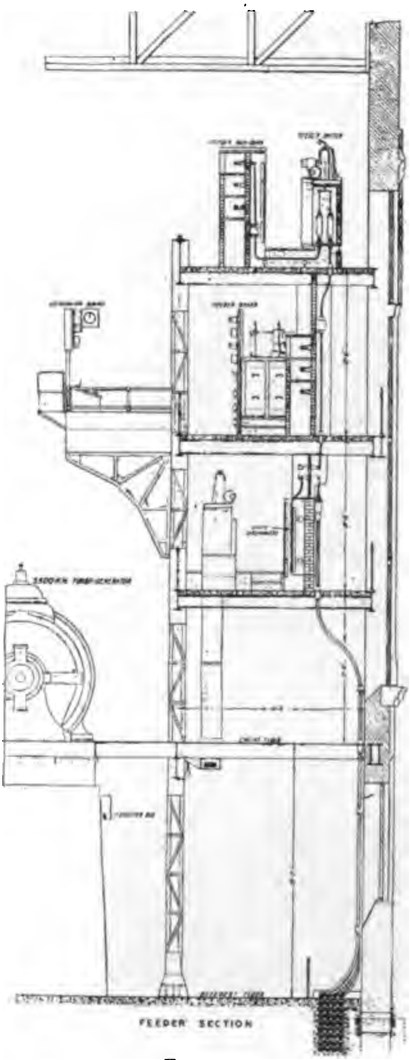


FIG. 409.

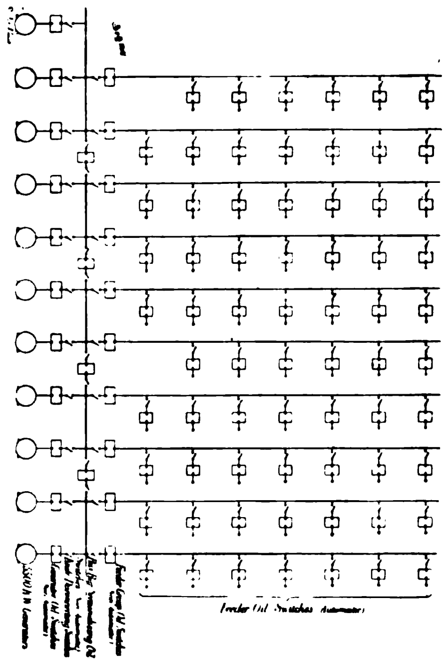


FIG. 410.

of 11,000 Volt Switch Gear and Cables, and Key Diagram. (*Street Railway Journal.*)

FIG. 411.—Lots Road, Chelsea: Feeder Switchboard.

These two boards are placed in the

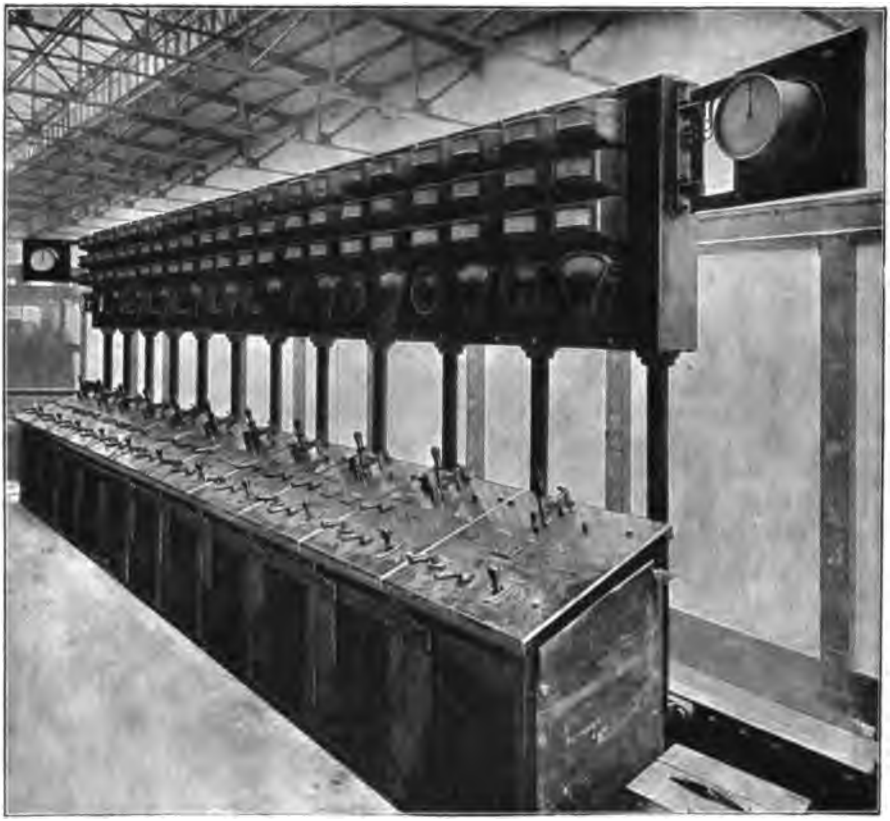


FIG. 412.—Generator Switchboard.

relative positions shown. (See Fig. 409, p. 605.) *Photos by B. T. H. Co., Ltd.*

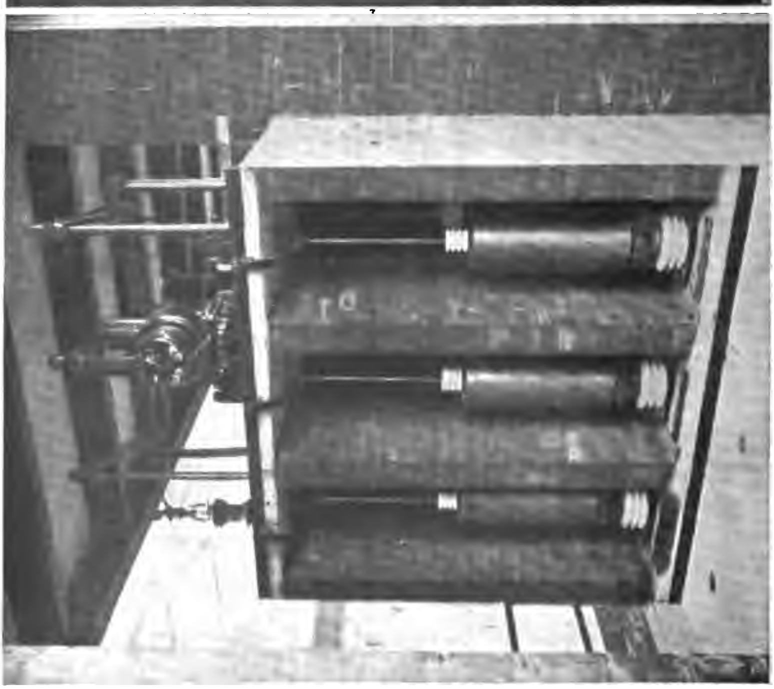


FIG. 413.—Lots Road, Chelsea: Bus Bar Sectionalising Oil Switch.

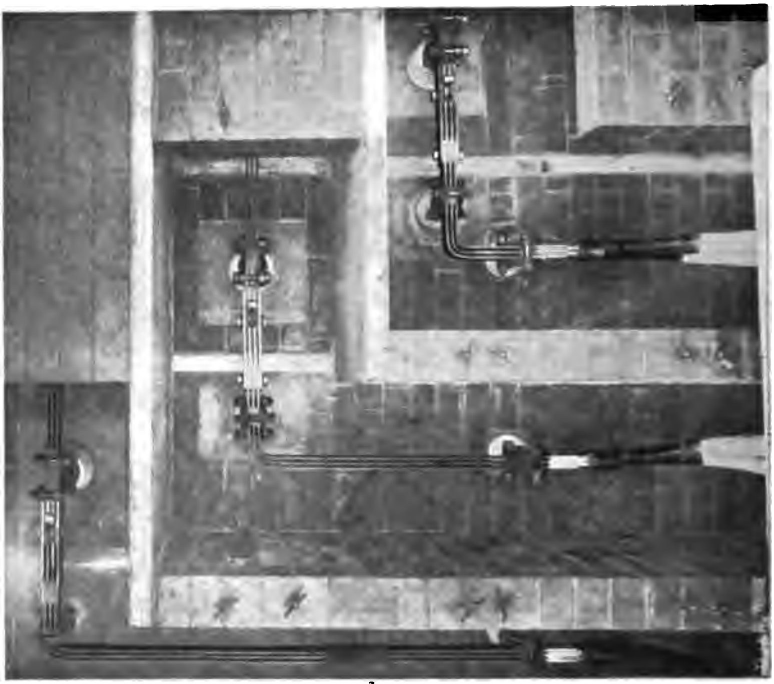


FIG. 414.—Knife Switches in Series, with each phase of each Oil Switch for isolating same.

(*Tramway and Railway World.*)

FIG. 415.—Lots Road, Chelsea : Motor operated Main Rheostats.
(*Tramway and Railway World.*)

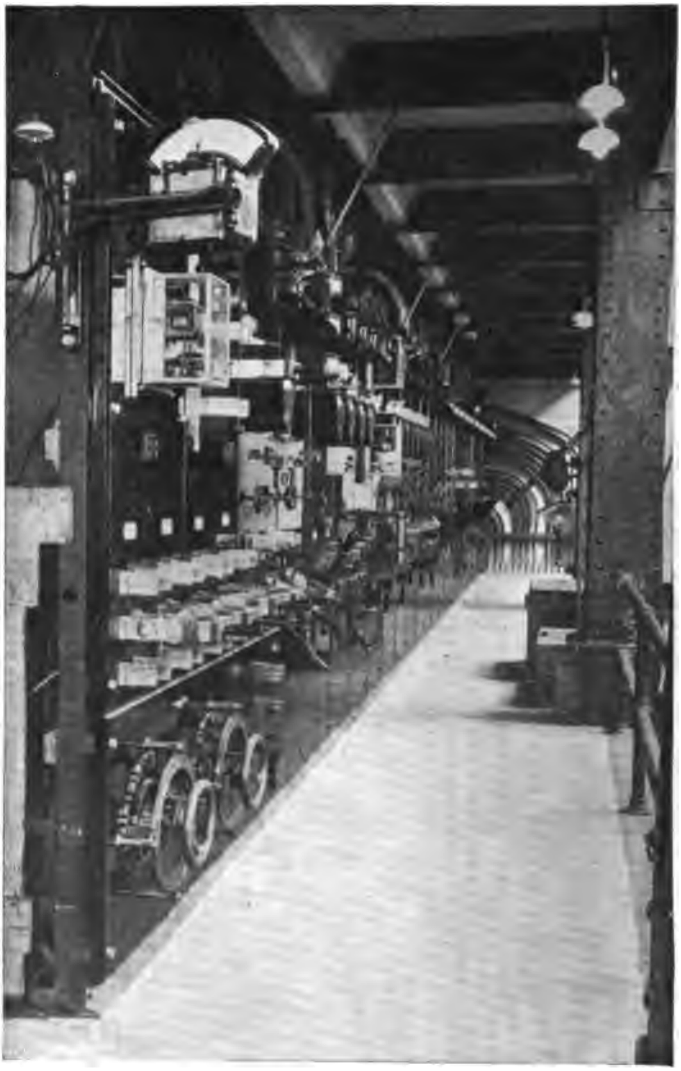


FIG. 416.—Lots Road, Chelsea: Auxiliary Plant Switchboard.
(*Tramway and Railway World.*)

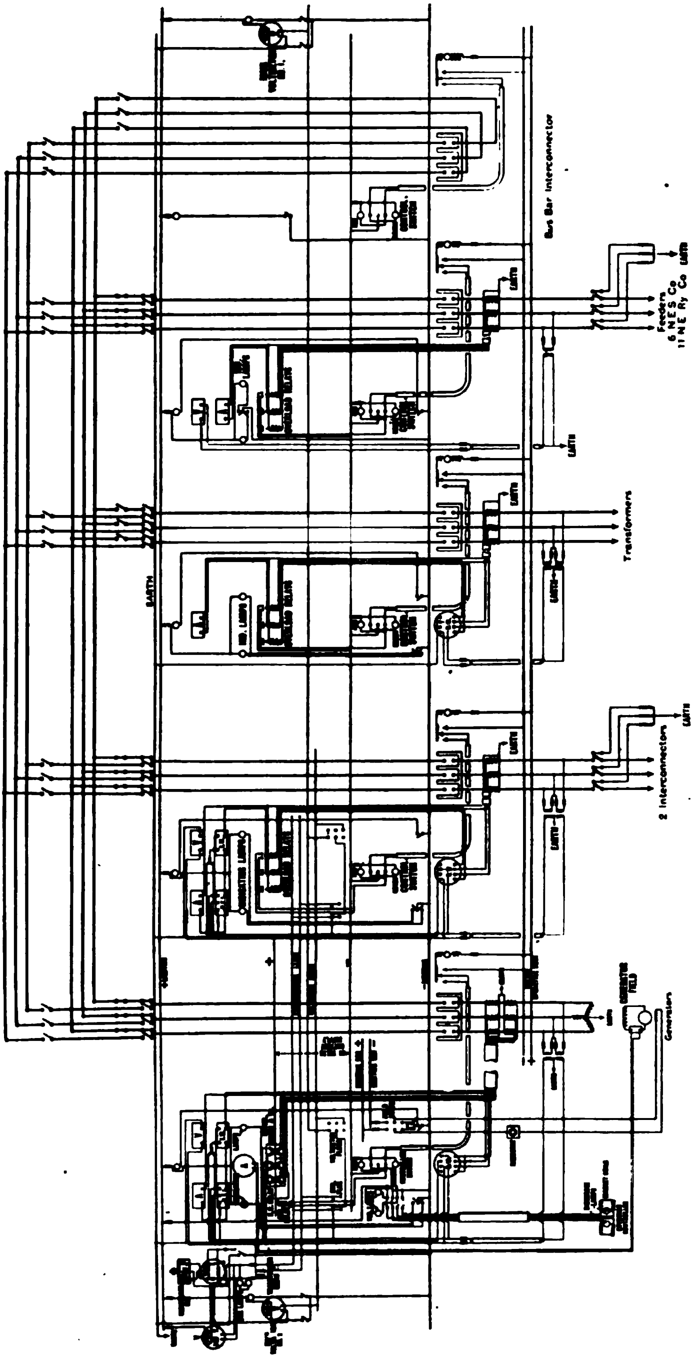
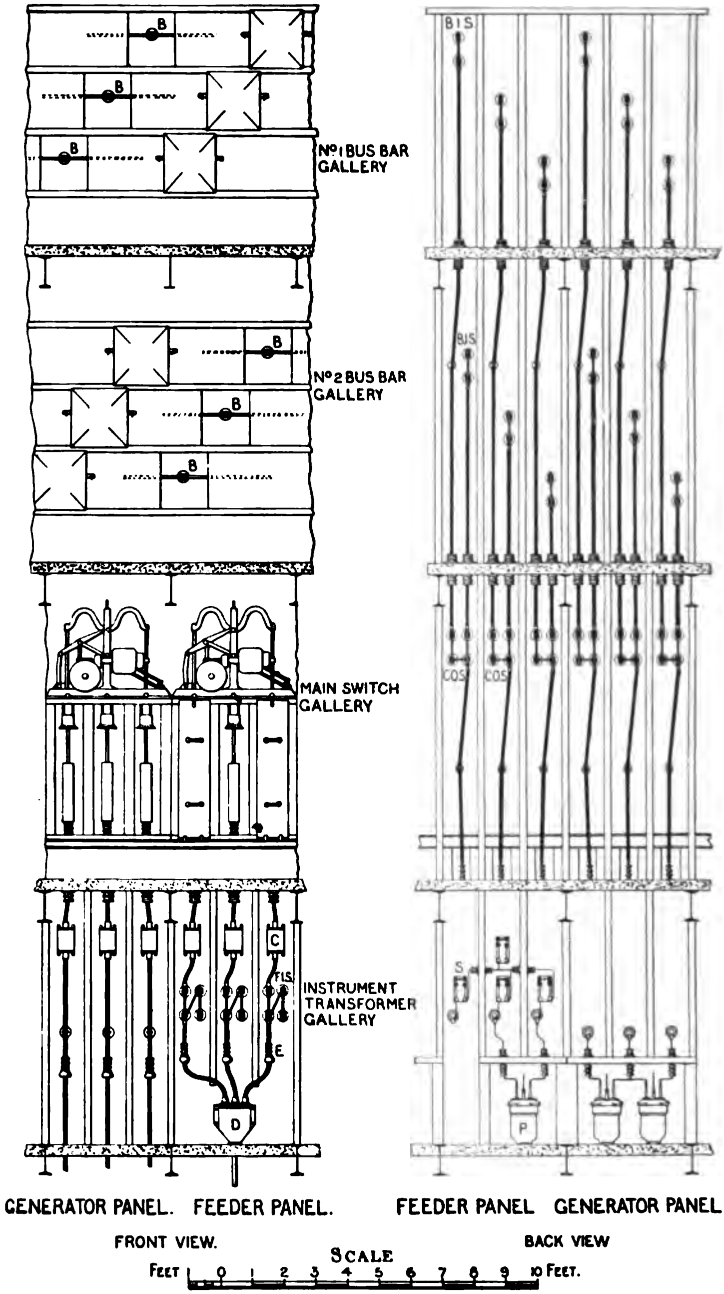


FIG. 417.—Carville: Wiring Diagram. (*The B.T.H. Co.*)

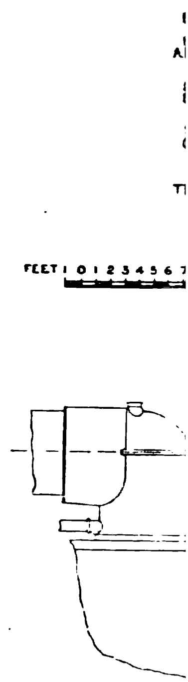


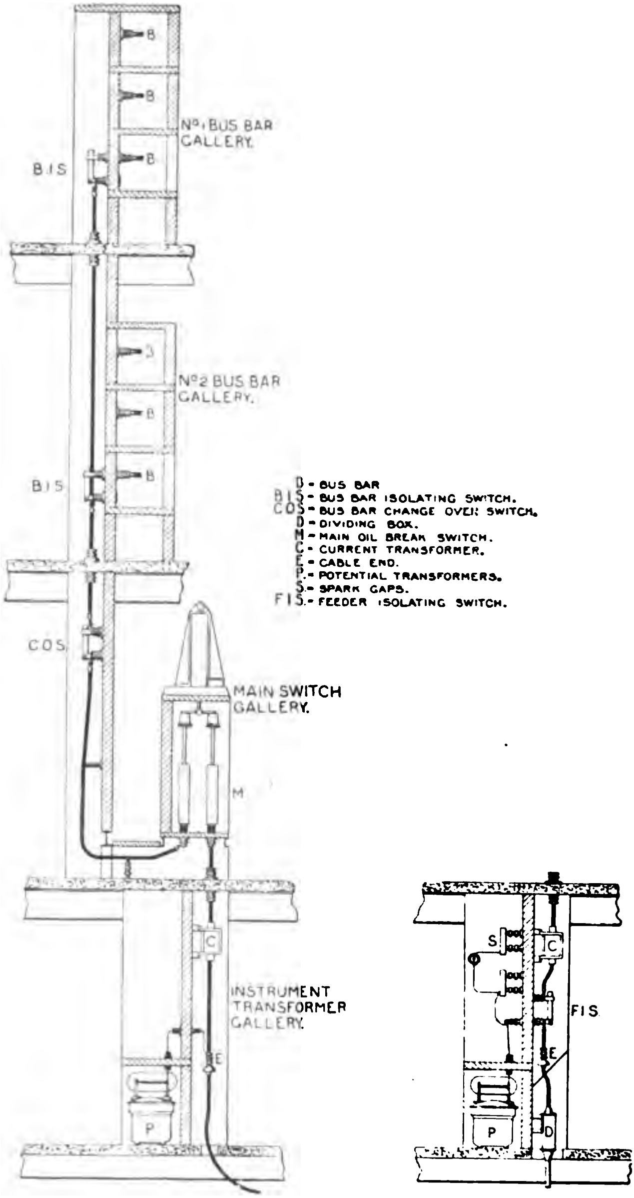
BACK AND FRONT VIEW OF H.T. SWITCH GEAR.
CARVILLE POWER STATION

FIG. 418. FIG. 419.

(From *Proc. Inst. Elec. Engrs.*)

GENERAL ARRAN





GENERATOR PANEL.

FEEDER PANEL

CROSS SECTION OF HIGH TENSION SWITCH GEAR.
CARVILLE POWER STATION.

SCALE
FEET 1 0 1 2 3 4 5 6 7 8 9 10 FEET.

FIG. 421. FIG. 422.

(From *Proc. Inst. of Elec. Engrs.*)

don

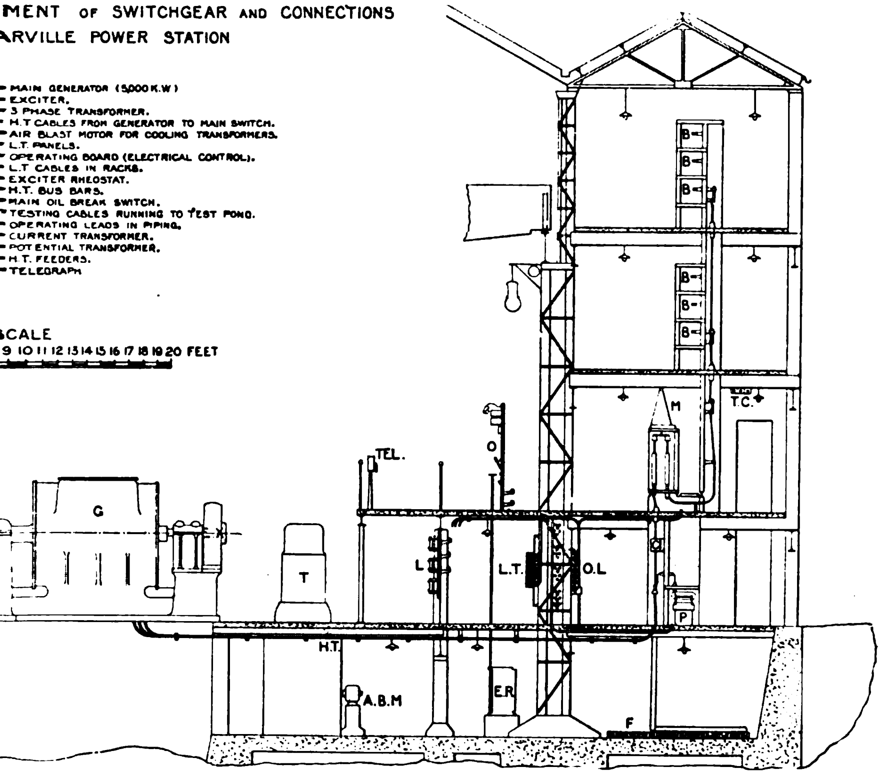


FIG. 420.
(From *Proc. Inst. of Elec. Engrs.*)

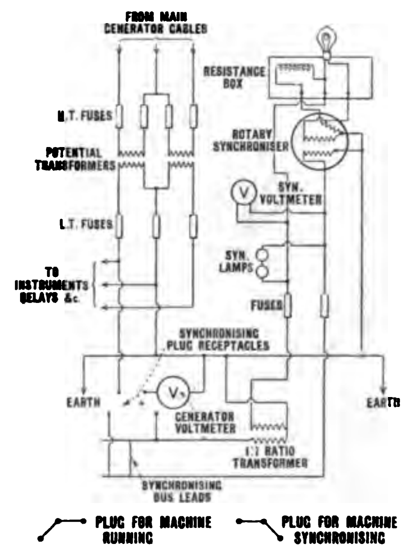
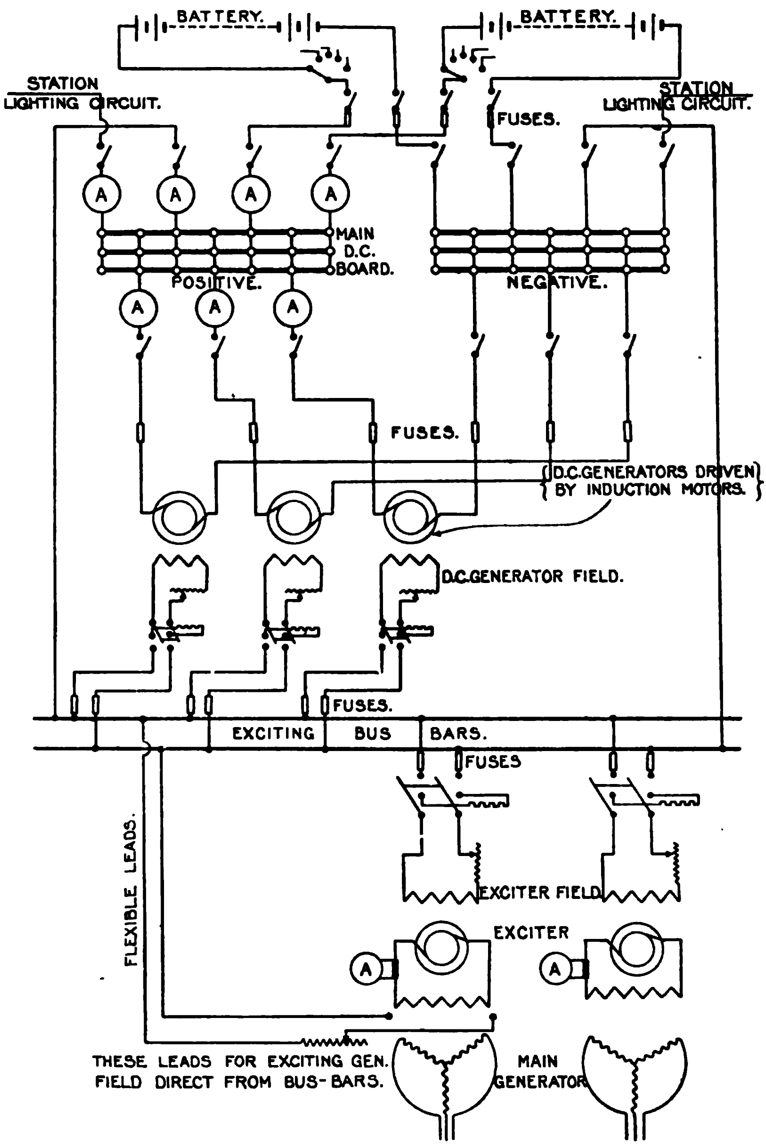


FIG. 423.—Carville Synchronising Connections.

:1 Ratio Transformer is used to give 'bright' lamps; synchronising being between two generator potential transformers with same pole earthed on each.

(*The Electrician.*)



EXCITING CIRCUIT DIAGRAM.
CARVILLE POWER STATION.

Fig. 424.

(*From the Inst. of Elec. Engrs.*)

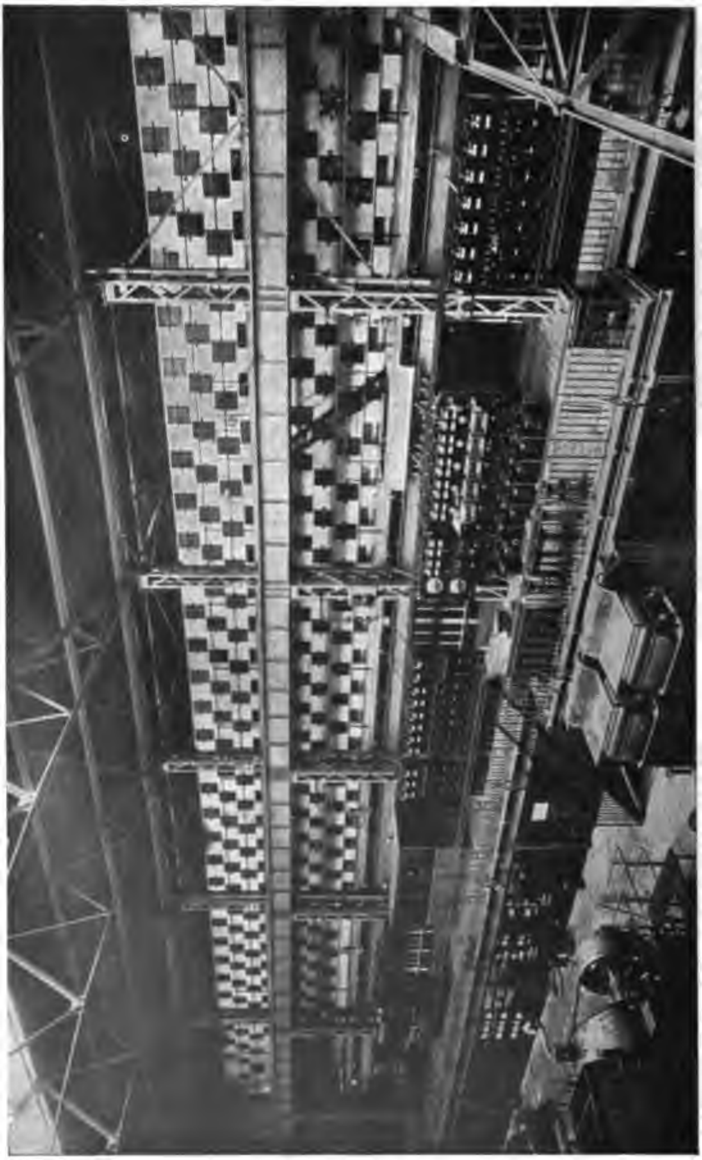


FIG. 425.—Carville Switchboard.

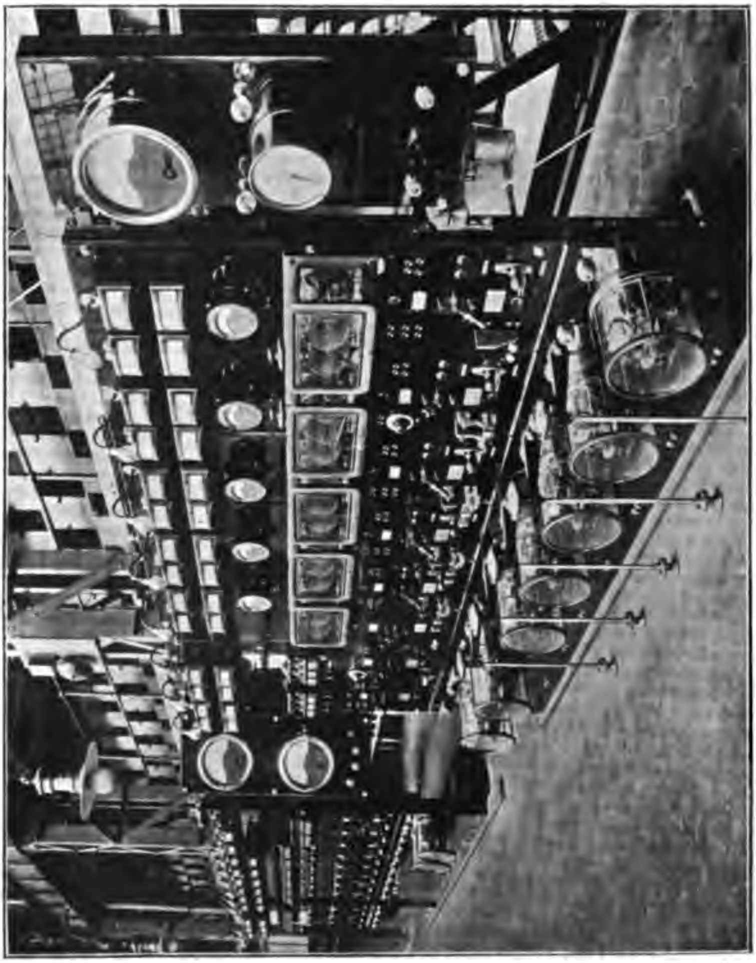


FIG. 426.—Carville: Main Generator Control Switchboard.

(*Photos by British Thomson-Houston Co.*)

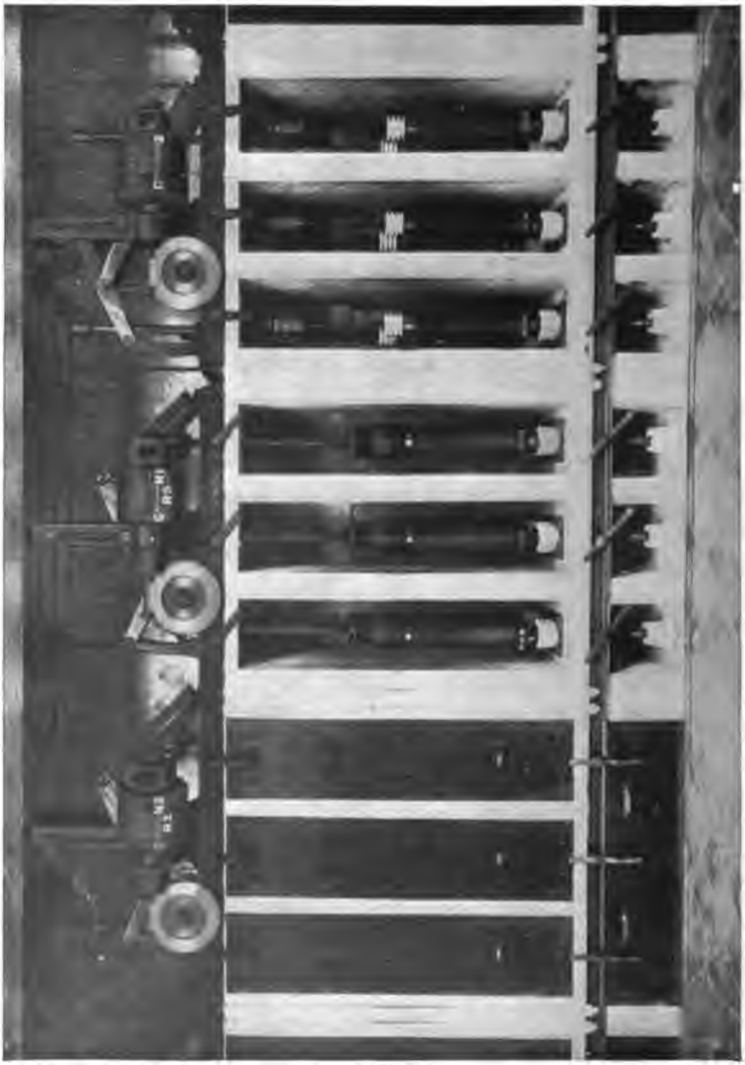


FIG. 427.—Carville: Motor-operated Oil Switches.

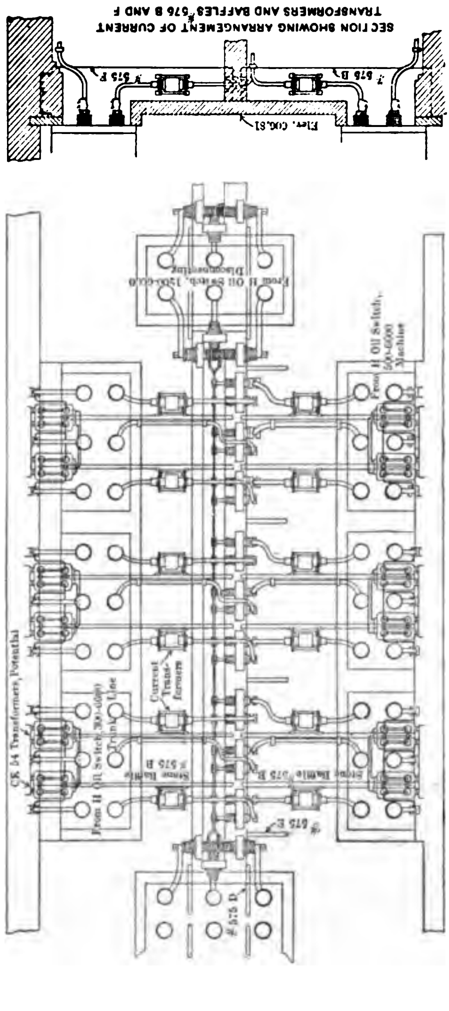


FIG. 428.—Delray, Detroit: Plan of Oil Switches, Disconnecting Switches, Transformers, and Cables. (*Elec. World and Engr.*)

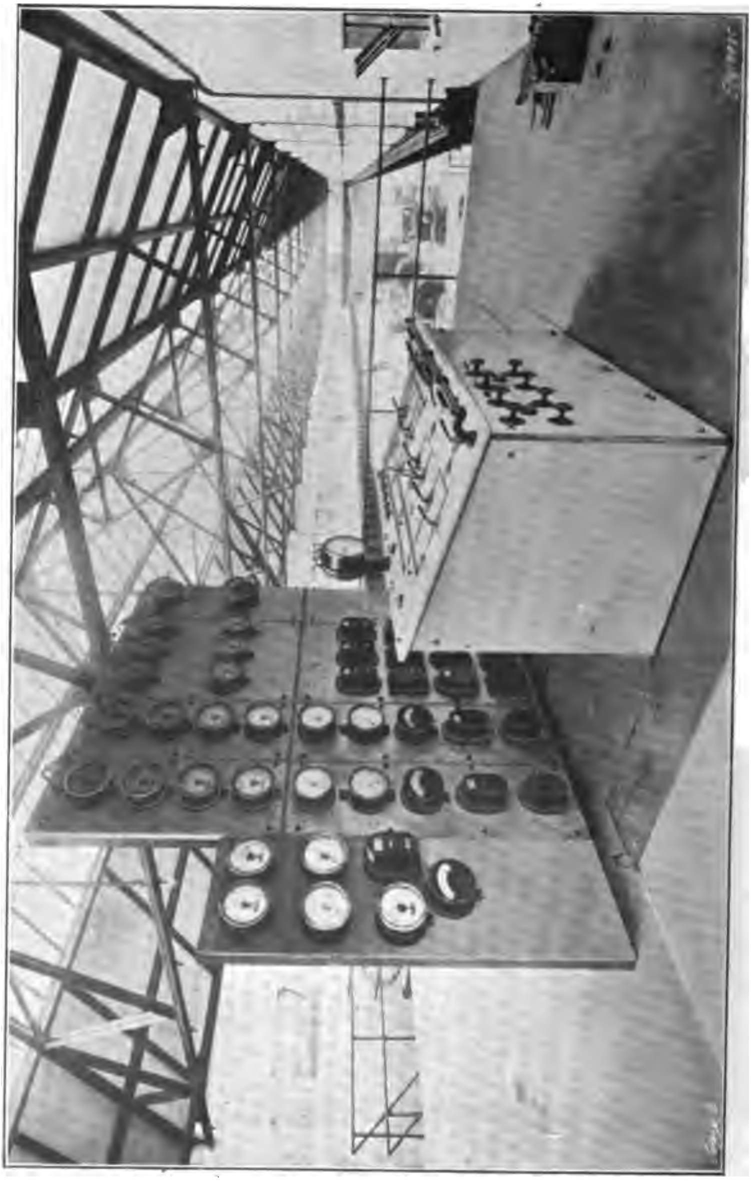


Fig. 429.—Yoker: Instrument and Control Switchboards. (*The Engineer.*)

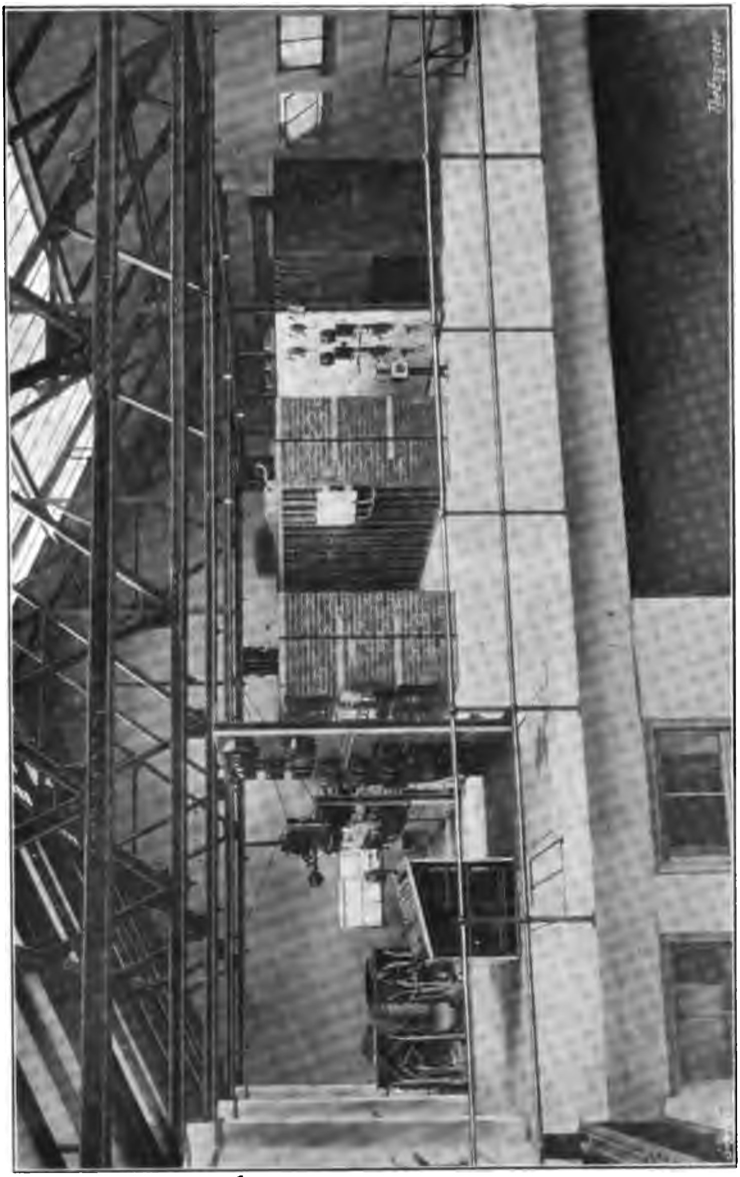


FIG. 480.—Yoker: Switchboard Gallery.

FIG. 431.—Quincy Point: Switchboards A.C. and D.C.

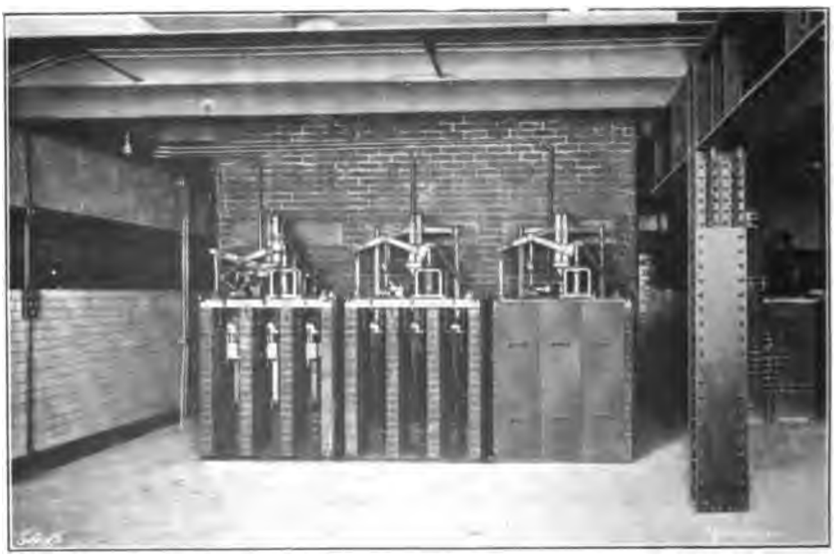


FIG. 432.—Yoker: High-tension Oil Switches.

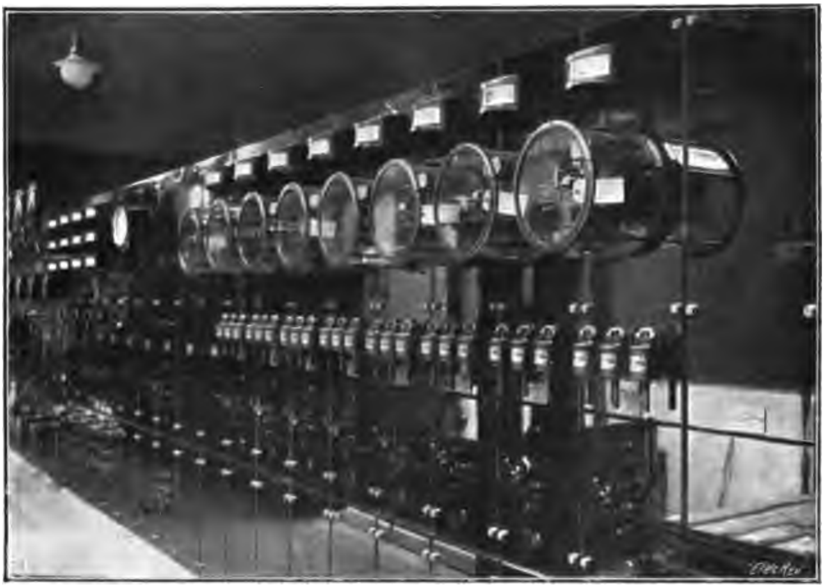


FIG. 433.—Thornhill: Main H.T. Feeder Panels.
(*The Electrical Review.*)

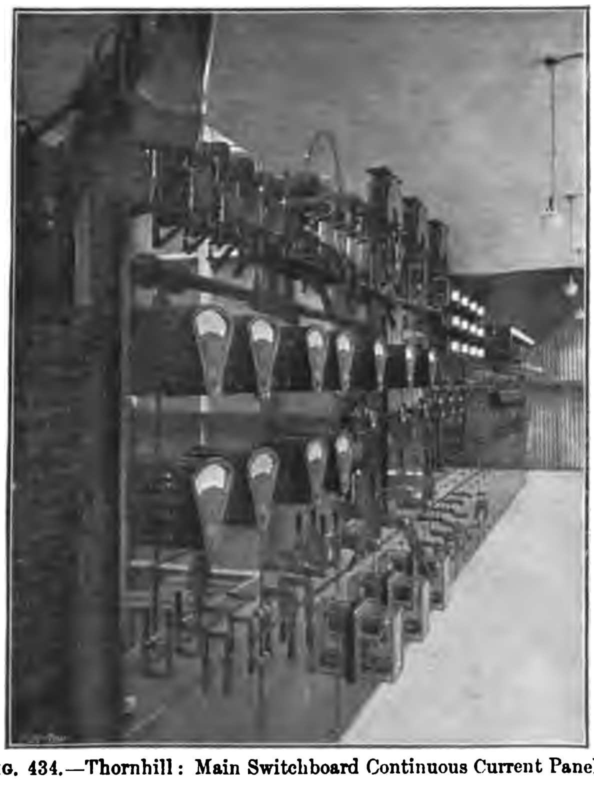


FIG. 434.—Thornhill: Main Switchboard Continuous Current Panels.

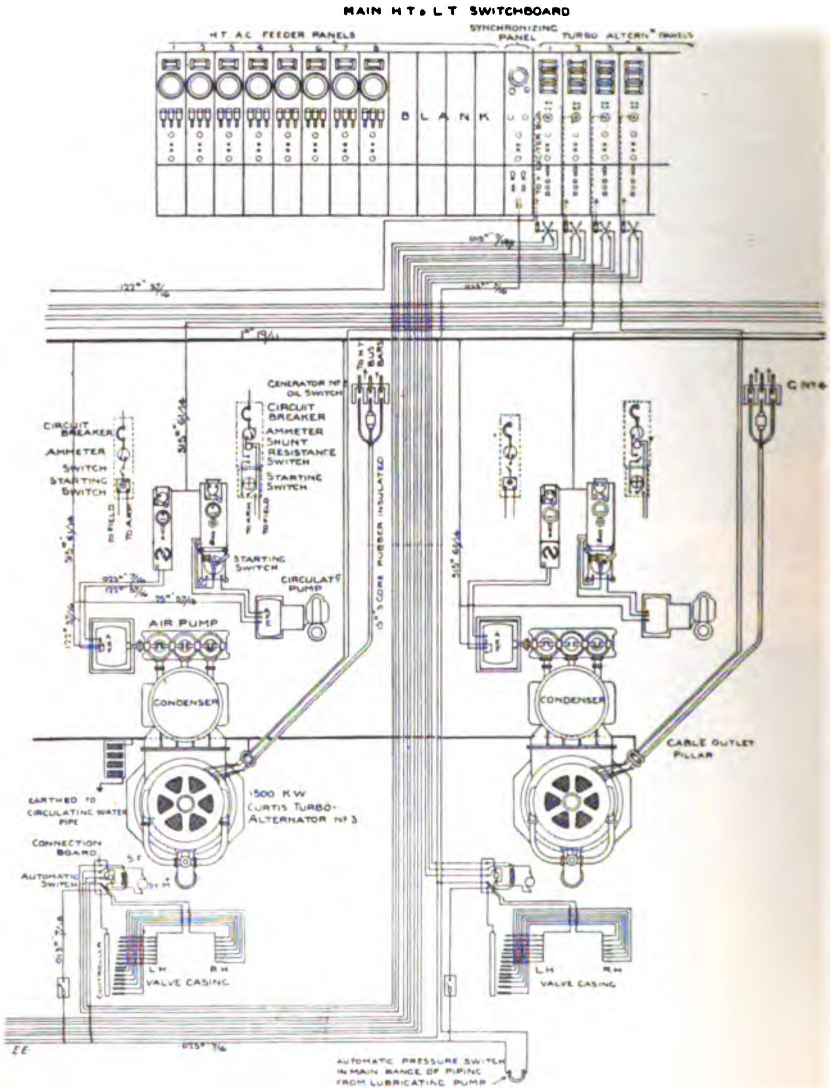


FIG. 435.—Radcliffe: Diagram of Electric Connections.

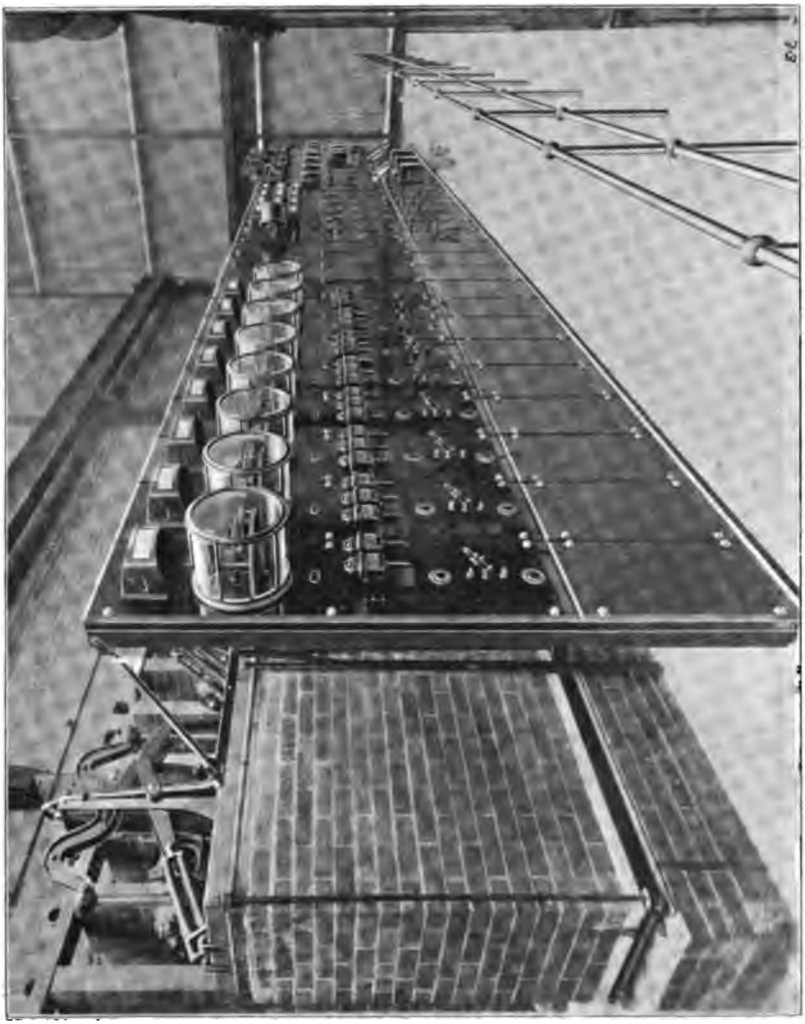


FIG. 486.—Radcliffe: Main Switchboard and Oil Switches. (*The Elec. Engr.*)

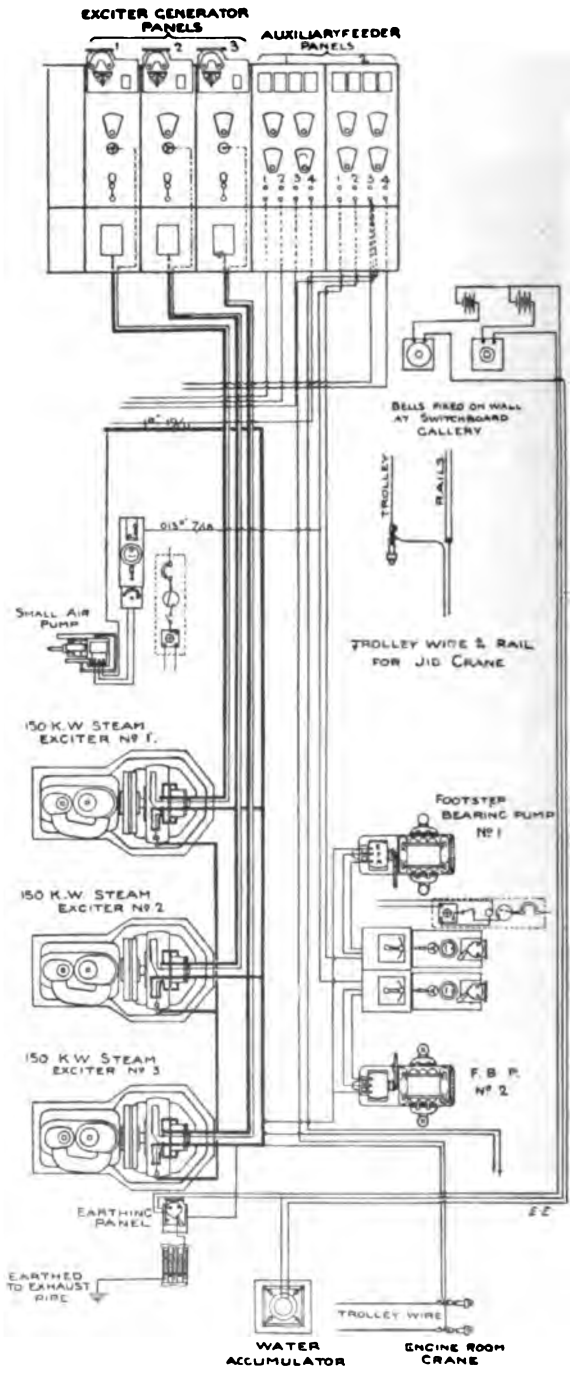


FIG. 437.—Radcliffe : Lancashire Power Co. : Diagram of Electric Circuits to Auxiliaries. (*The Elec. Engr.*)

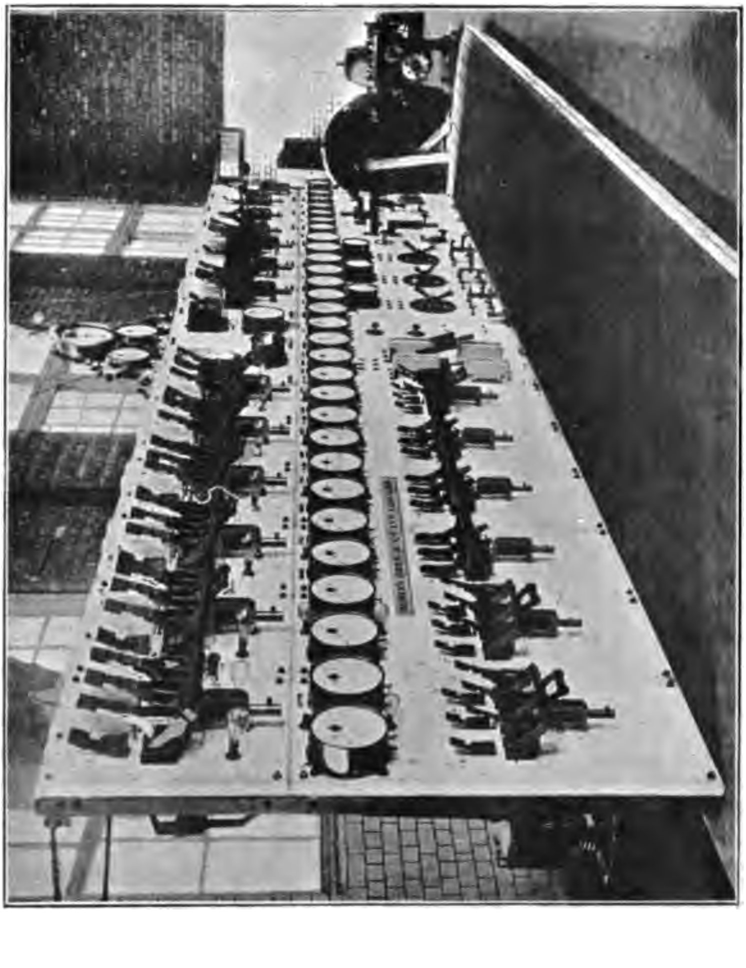


FIG. 487A.—English M'Kenna Co.'s Main Switchboard.

All the data on this plant was kindly supplied by Mr F. A. Knight, Chief Engineer to the Company.

Name of Generating Station	Lots Road, Chelsea. [*From p.* 594.
75. Transformers:	
Number	3 sets.
Maker	Westinghouse.
Type	
Volts primary	11,000.
Volts secondary	220.
K.W. rating	
Number of Sets	
Connection	
Supplying	Motors for auxiliary plant.
76. Auxiliary Alternate Current **Generating Plant**	None.
Takes Steam through	
Exhaust into	
Engine: Number	
Maker	
Type	
Speed	
Lubrication	
Generator: Number	
Maker	
Rating	
Voltage	
Phases	
Use	
77. Auxiliary Pumps	
Number	
Maker	
Connected	
Capacity, Larger	
Smaller	
Pumping against head	
Steam received from	
Steam exhausts into	
Used	

[*Lots Road, Chelsea, ends.*

	Neasden.	**Carville.** [*From p.* 595.
75.		
	4.	2.
	Westinghouse.	
	Oil-cooled.	
	11,000.	6000.
	440.	480.
	50 K.W.	750 K.W., 3 phase each.
	2.	2.
	Y.	Δ on h.t. side, Y on l.t. side.
	Motors of auxiliary plant and local lighting.	Motors of auxiliary plant.
76.		None.
	Pipe from main header.	Two inter-connection panels (6 single core cables) join Neptune Bank (an older separate power-house) in parallel with Carville.
	Alberger surface condenser.	
	1.	
	Westinghouse.	
	Single-acting compound.	
	286 R.p.m.	
	Bearings run in enclosed oil bath.	
	1.	
	Westinghouse.	
	100 K.W.	
	440.	
	3.	
	This set is used to run the auxiliary motors for economiser, conveyor, etc., if for any reason the supply through the static transformers from the main bus-bars ceases.	
77.		
	2.	
	Frank Pearn & Co.	(For cleaning switch gear compressed air is supplied on all galleries through permanent pipes from motor-compressor in basement. Armoured hose with long insulating nozzles are attached to any of the cocks provided.)
	In parallel.	
	40,000 gallons per hour one.	
	10,000 ,, ,, the other.	
	8 feet.	
	Main header.	
	Feed-water heaters.	
	Either singly or together, instead of any of the circulating pumps, or connected to the fire mains throughout the buildings.	
	[*Continued on p.* 628.	[*Carville ends.*

Name of Generating Station	Neasden. [From p. 627.
78. **Substation:**	
In Power-house	
Situation	In basement below the level of the generator-house floor.
79. **Transformers:**	
Number	12.
Maker	Westinghouse.
Capacity	200 kilowatts each.
Type	Oil-insulated—self-cooling.
Regulation	1·75 per cent. no load to full load.
Voltage	11,000 primary per phase, 440 secondary per phase.
Maximum Temperature rise	
Full load	45° C. for 24 hours.
25 per cent. overload	60° C. for 24 hours.
50 ,, ,,	60° C. for 1 hour.
Efficiencies guaranteed	
½ load	97 per cent.
¾ load	97·4 per cent.
Full load	97·4 per cent.
Controlled	From high-tension substation switchboard through oil switches.
80. Rotaries	
Number	3.
Type	Compound-wound.
Makers	British Westinghouse Co.
Capacity	800 kilowatts each.
Number of Poles	10.
Efficiencies guaranteed	
½ load	91½ per cent.
¾ load	94 per cent.
Full load	95 per cent.
Pole pieces	Laminated steel.
Armature	Slotted drum.
Maximum Temperature rise guaranteed	
Normal load	40° C. 24 hours.
25 per cent. overload	50° C. 24 hours.
50 ,, ,,	60° C. 1 hour.
Starting arrangement	Induction motor on extended shaft on end of rotary bed-plate.
Brushes	Carbon for continuous current, copper for alternate current.

[Neasden ends.

Quinoy Point, Mass., U.S.A.

[*From p.* 597.

Fig. 363.

On one side main turbine room.

3.
General Electric Co., Schenectady.
825.
Air blast, 3 phase.

1 auxiliary transformer 3 phase supplies 350 volts to drive exciters, blowers, condensers, conveyor motors.

3.
Compound.

750 K.W., 25 cycles, 600 volts.

[*Quincy Point ends.*

CHAPTER XXIII

MARINE STEAM TURBINES

Limits of the Subject.—The purpose in view is to bring together as much data on the application of the steam turbine to marine work as those who have the information are willing to have published. The following list of vessels gives some details and references to further tabulated data. It is not surprising that all builders and users of vessels have not time and inclination to supply every detail necessary to make any outlined scheme complete. Appreciation of the assistance received from many of them is expressed in the Preface.

LIST OF TURBINE VESSELS AND INDEX TO FURTHER DATA.

Item Number.	Turbine-Vessel's Name.	Launched.	Speed.	H.-P.	R.P.M. Centre Shaft.	R.P.M. Side Shaft.	Boiler Pressure lbs. per sq. in.	Superheat.	Vacuum Inches of Mercury.	Further Details on page—
1	"Turbinia 1st" .	1894	34·5	2,000	2230	..	210	None	?	636
2	"Viper" . . .	1898	37·1	12,300	1180	..	240	,,	?	659
3	"Cobra" . . .	1899	34·6	13,000	1050	..	240	,,	?	659
4	"King Edward" .	May 16, 1901	20·5	3,500	500	7508	150	,,	26½	664
5	"Queen Alexandra"	Apr. 8, 1902	21·6	4,400	750	1100	150	,,	26½	664
6	"Revolution" . .	1902	18	1,800	650	..	250	,,	28	728
7	"Velox" . . .	1902	27·1	9,000	..	840T	200	,,	27	659
	,, max. .	..	36·6	12,000	..	1180	..			
8	"No. 243" . .	1902	21	1,800	..	..	250		..	735
9	"Tarantula" . }	1902	26·7	..	..	..	225	,,	..	673
			22	2,000	1000	930	..		21	
10	"Emerald" . .	Oct. 2, 1902	15	..	500	700	150	,,	?	669
11	"Eden" . . .	Mar. 14, 1903	26·3	7,500	940	..	250		..	659
12	"Queen" . . .	Apr. 4, 1903	22	9,700	480	500	150	,,	?	684
13	"Lorena" . .	1903	18	3,500	550	700	180		..	669
14	"Brighton" . .	1903	21·5	7,000	520	600	150	,,	?	685
15	"Amethyst" . .	Nov. 5, 1903	23·6	14,000	449	490	260	,,	27	648
16	"No. 1125" . .	1903	26·4	2,000	*575R*	1850T	..		..	673
17	"Princess Maud" .	Feb. 1904	20·6	6,000	600	..	150		..	664
18	"No. 293" . .	Mar. 17, ,,	26	1,950	..	..	250		..	735
19	"Lübeck" . .	Mar. 26, ,,	23·9	12,000	650	..	..	,,	..	742
20	"Turbinia (2nd)" .	Mar. 30, ,,	18·5	5,000	..	..	160	,,	27½	728
21	"Manxman" . .	June 15, ,,	23	8,500	530	600	200		28½	692
22	"Londonderry" .		22·3	8,000	650	750	150	,,	28	692
23	"Victorian" . .	Aug. 25, ,,	19·5	12,000	300	300	180	,,	?	710
24	"Lama" . . .	Dec. 8, ,,	17	4,000	..	..	150		?	685

LIST OF TURBINE VESSELS AND INDEX TO FURTHER DATA—*continued.*

Item Number.	Turbine-Vessel's Name.	Launched.	Speed.	H.-P.	R.P.M. Centre Shaft.	R.P.M. Side Shaft.	Boiler Pressure lbs. per sq. in.	Superheat.	Vacuum Inches of Mercury.	Further Details on page—
25	"Narcissus" . .	Dec. 20, 1904	14·5	1,250	550	..	180	None	?	669
26	"Virginia" . .	Dec. 22, ,,	19	11,000	270	..	180	,,	?	710
27	"Albion". . .	Dec. 22, ,,	15	1800	..	..	150	,,	?	669
28	"Caroline" . .	,,	26·4	2200	*516R*	1450T 1650	235	,,	27	673
29	"Linga" . . .	,,	18	4,000	..	..	150	,,	?	685
30	"Lunka". . .	,,	17	4,000	..	..	150	,,	?	685
31	"Lhassa" . .	,,	18·1	4,000	..	..	150		..	685
32	"Loongana" . .	,,	20·1	6,000	650	..	150	,,	?	685
33	"No. 294" . .	,,	18	..	..	..	..		..	735
34	"Howaldt's" . .	,,	..	..	..	..	..		..	742
35	"S 125" . . .	,,	28·9	7,000	..	..	..		..	742
36	"Libellule" . .	(?)			..	..	..	,,	..	669
37	"Carmania" . .	Feb. 21, 1905	21	22,700	..	..	195	..	(?)	716
38	"Viking" . .	Mar. 7, 1905	..	..	..	..	150	..	..	664
39	"Onward" . .	Mar. 11, 1905	..	..	..	..	..	..	..	684
40	"Independance" .		23	12,000	..	..	..	..	..	734
41	"Princesse Elizabeth"	Mar. 30, 1905	24	..	..	..	150	..	..	734
42	"Dieppe". . .	Apr 6, 1905	21·5	7,000	600	..	150	..	(?)	685
43	"Kaiser". . .	Apr. 8, 1905	20·5	6,000	600	..	200	..	..	742
44	"Invicta" . .	Apr. 19, 1905	23	8,000	..	..	150	..	..	684
45	"Wacht". . .	1905	..	..	..	..	..	..	(?)	742
46	U.S.A. "Cruiser" .	1905	..	..	..	..	..	..	..	728
47	U.S.A. Scout "Salem"	1905	24	16,000	..	..	..	..	..	728
48	U.S.A. Scout "Chester"	..	24	16,000	..	..	..	..	..	728
49	"St George," G.W.Ry.	Jan. 13, 1906	..	..	..	..	..	..	..	..
50	"St Patrick," ,,	...	23	9,000	430	..	160	..	..	664
51	"St David," ,,	Jan. 26, 1906	..	..	..	..	..	..	..	..
52–3	G.C. Ry. Co. . .	..	18	6,500	..	..	Two by Messrs Cammell Laird & Co. 270ft. long, 16ft. draught, 3 shafts.			
54	"Susitania" . .	25-knot vessel	25	75,000	160	..	..	..	..	716
55	"Mauritania" . .	25-knot vessel	..	75,000	..	..	..	..	..	716
56	Cunard, knot .	Vessel	..	60,000	..	..	..	..	..	716
57	"T. B. Taylor . .	Vessel	..	..	..	..	..	..	..	31
58	"Maheno . . .	1905	17·5	6,000	..	..	175	..	(?)	685 footnote
	Vancouver to Sydney.									
59	"Bingera" . .	..	..	6,000	..	..	..	..		,,
60	"Osborne"[1] . .	..	18							
61	"Mahroussa"[2]. .	..	17·5	..	..	..	..	..	,,	,,
62	British Battleships .	..	..	..	Four	Shafts	..	..	,,	,,
	"Dreadnought" Class[3]	Feb. 10, 1906	21	28,000	300	..	250	..	,,	,,
	British Torpedo Boats									
63	5 Ocean Destroyers[4]	..	33	1,500	700	..	220	..	,,	..
64	2 Ocean Destroyers .	..	31	..	..	..	..	..	,,	..
65	12 Coastal Destroyers[5]	..	26	3,600	1200	..	220	..	,,	..
66	P. A. Campbell, Esq., Bristol	..	20	..	..	..	..	..	,,	..

[1] H.M. King Edward VII.'s Yacht, 2000 tons, 285ft. long, 40ft. wide, Parsons Turbines by Messrs A. & J. Inglis, Pointhouse. [2] H.M. The Khedive of Egypt's Yacht.

[3] Four propellers, each 111ins. diam. on four shafts, 18,000 tons, 26ft. draught, nearly 500ft. by 82ft. beam. 2 rudders 20ft. apart. 2 h.p. for'd and astern turbines (Vickers) on two wing shafts; 2 l.p. for'd and astern, also 2 cruising turbines on 2 inside shafts. Babcock boilers for coal or oil fuel. 21 knots.

[4] By Messrs Laird, Thornycroft, Armstrong, Hawthorn Leslie. 250ft. long with a 72in. diam. propeller on each of 3 shafts.

[5] 175ft. long with a 36in. diam. propeller on each of 3 shafts. "Grasshopper," "Gadfly," "Glow-worm," "Greenfly," "Gnat," each 230 tons, by Messrs Thornycroft & Co., Chiswick, London. "Moth" and "Mayfly," each 230 tons, by Messrs Yarrow & Co., Millwall. "Cricket" (launched Jan. 23, 1906), "Dragonfly," "Firefly," "Sandfly," "Spider," each 220 tons, by Messrs J. T. White & Co., Cowes.

LIST OF TURBINE VESSELS AND INDEX TO FURTHER DATA—*continued.*

Item Number.	Turbine-Vessel's Name.	Launched.	Speed.	H.-P.	R.P.M. Centre Shaft.	R.P.M. Side Shaft.	Boiler Pressure lbs. per sq. in.	Superheat.	Vacuum Inches of Mercury.	....
67	General Steam N. Co. "Kingfisher" *Tilbury, etc. to Boulogne.*	Mar. 27, 1906.	21		One by Messrs Denny.					
68	Burn Line . . . *Ardrossan to Belfast.*	..	..		One by Messrs Fairfield & Co.					
69	"Creole" . . . . *Morgan Line, Southern Pacific Ry.*	.	15(?)		(10,000 tons, 440ft. long, 53ft. beam, Curtis Turbines).					
70	Hamburg-Heligoland S.S. Co.	..	20	6,000	One by "Vulcan," p. 748.					
71	Caledonian Steam Packet Co.	? One by Messrs Denny.								
72–3	Allen Line . .	Two larger than "Victorian" or "Virginian."								
74	Coast Development Co., London (Belle Steamers).	One for River Thames by Messrs Denny.								
75	Metropolitan S.S. Co., New York	Two by Messrs Roach, Chester, Pa., U.S.A.								
76	Eastern S.S. Co., U.S.A.	One by Messrs Roach, Chester, Pa., U.S.A.								

Condensers, etc.—Table CXIII., p. 437, gives the surface of Marine Condensers, Steam per hour, and per square foot of condenser surface and ratios of condenser surface to boiler heating surface, and of the latter to grate area for turbine vessels, so far as these have been ascertained.

Comparisons with Reciprocating Engines.—An effort has been made to put alongside the tabulated data on turbine-driven vessels dimensions of the reciprocating-engined vessel which runs on the same route and is nearest in size to the turbine vessel.

In most cases this is incomplete, but in every case care has been taken to avoid any confusion of the two by using distinctive type.

The turbine was considered theoretically superior at high speeds to the reciprocating engines, and the Hon. C. A. Parsons' earliest work used 2200 revolutions per minute, but the speed has been reduced rapidly, and we have 300 revolutions on the Allan liners and 180 revolutions as specified maximum on the new Cunard liners, with about 160 actual.

Limits of Speed and Size.—From the report of Professor Rateau's paper before the Institute of Naval Architects, March 25th, 1904, the following is outlined:—

1. The total surface (size) of propellers is mainly determined by the principal cross section of the ship.

2. The size of the turbines is limited only by the speed of rotation, and not by the power developed.

3. The speed of the turbine must be reduced in proportion to the speed of the ship, so the dimensions of the turbine are increased (either by increasing the number of rings or by increasing their diameter).

4. The power increases approximately as the cube of the speed of the vessel.

5. There is a lower limit of speed, below which the use of steam turbines alone cannot be recommended.

6. Professor Rateau, in his paper before the Association Technique Maritime in 1902, put this speed limit at about 20 knots for turbines alone.

7. For reciprocating engines and turbines the same authority fixes this limit at "15 knots, or even less."

8. Clearances between moving and fixed parts in the Rateau type of turbine generally exceed 3 millimetres, and may even be 5 to 6 millimetres.

Other Opinions on the Lower Limit of Speed for Turbine Vessels.—Sir William White did not accept Mr Rateau's limit of 20 knots, and stated he had been designing a yacht with turbine engines which would have an economical speed at 12 to 13 knots, the maximum speed being considerably higher.

Sir William White was one of the Commission of Experts appointed by Lord Inverclyde and the other directors of the Cunard Company to consider the question of turbines *versus* reciprocating engines for their latest vessels.

Cunard Commission.—The complete list of members of that Commission in alphabetical order is—

1. Mr James Bain, Marine Superintendent of Cunard Company.

2. Mr T. Bell, Engineer-Director of Messrs John Brown & Co., Ltd.

3. Mr H. J. Brock, of Messrs Denny, Dumbarton.

4. Mr Andrew Laing, Managing-Director of the Wallsend Engineering Co.

5. Mr J. T. Milton, Chief Engineer-Surveyor of Lloyd's.

6. Engineer-Rear-Admiral H. J. Oram, Deputy Engineer-in-Chief of the Royal Navy.

7. Sir Wm. H. White, K.C.B., representing Messrs C. S. Swan & Hunter, Ltd., Newcastle-on-Tyne.

Professor Rateau's limit of 20 knots is evidently not accepted by

The Parsons Marine Steam Turbine Company, as they have equipped the *Lorena*, *Princess Maud*, *Tarantula*, *Turbinia* (the one for Canadian river service), *Lhasa*, *Linga*, Allan liners, and the *Albion*, etc., with turbines for lower speeds than 20 knots.

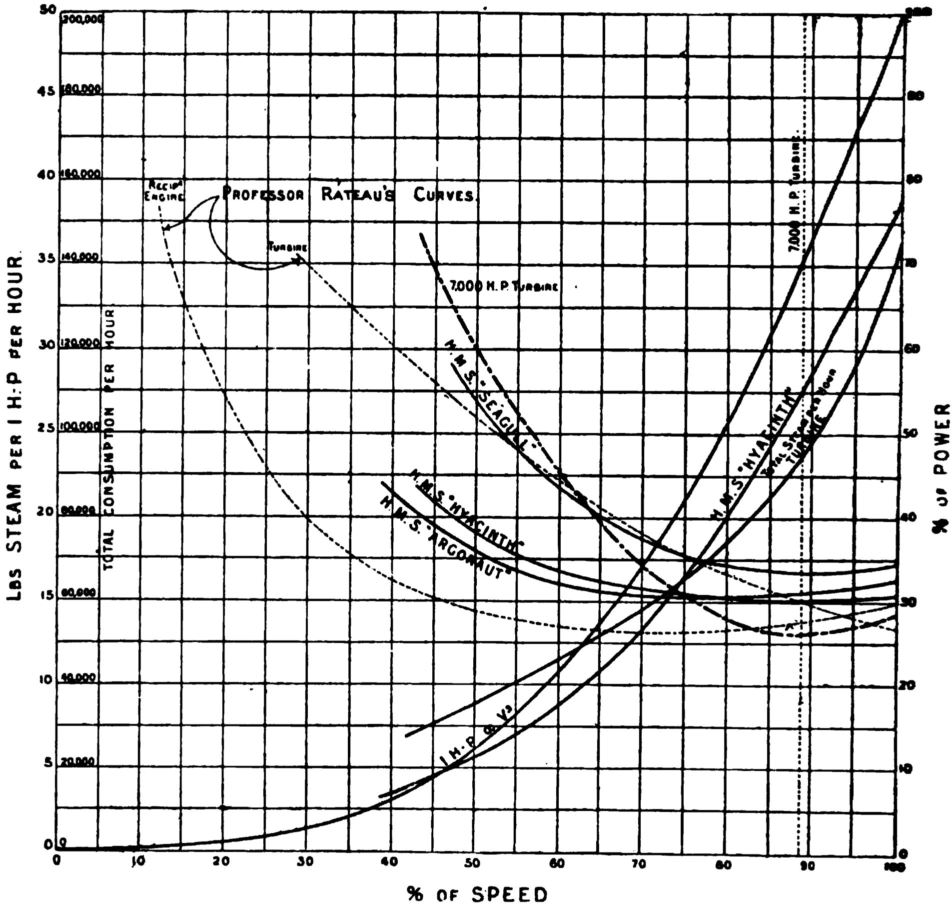


FIG. 438.—From *Proceedings Inst. Naval Architects.*

Relative Consumption of Steam: Turbines *versus* **Reciprocating Engines.**—Fig. 438 includes Professor Rateau's roughly approximate comparison of the general variation of steam consumption per H.P.H. for a turbine and a reciprocating engine, assuming they consume equal quantities of steam at the maximum speed. The steam consumption of the reciprocating

engine is below that of the turbine for all comparative speeds up to about 95 per cent.

In the discussion of Professor Rateau's paper Mr E. M. Speekman considered those curves somewhat elusive, and put forward Fig. 438, which repeats Professor Rateau's curves and includes curves showing the steam consumption per H.P.H. from no speed to full speed of the following:—

Professor Rateau's Turbine.
Professor Rateau's Reciprocating Engine.
Torpedo gunboat H.M.S. *Seagull.*
Cruiser H.M.S. *Hyacinth.*
Cruiser H.M.S. *Argonaut.*
Westinghouse (Pittsburgh) guarantees on a 7000 horse-power turbine at 740 revolutions per minute.

It also includes curves showing total steam consumption per hour for all speeds (zero to full speed) of H.M.S. *Hyacinth* and of the 7000 horse-power turbine; and a curve, varying as the cube of the speed or velocity (V^3), connecting percentages of speed and percentages of power (this refers to scale on right-hand of figure).

This 7000 horse-power Westinghouse Pittsburgh turbine had

Steam pressure	170 lbs.
Superheat	none.
Vacuum . . .	27 inches of mercury.

Limit of Vessel's Speed.—Mr Speekman claimed that no vessel except torpedo craft, and these only rarely, can steam below 33 per cent. of their full speed, because steerage-way cannot be maintained, and very few can steam below 40 per cent. His curves therefore do not go below this limit. He gave the mean speed of larger vessels, such as battleships and cruisers, as 20 knots, and showed that the steam consumption of the 7000 H.P. turbine at 65 per cent. of its full speed (corresponding to 13·5 knots) equalled that of H.M.S. *Seagull*, and at 75 per cent. of its full speed it equalled in steam consumption per H.P.H. the engines of H.M.S. *Hyacinth*, and H.M.S. *Argonaut*, though the two last named consume 16 per cent. less than the 7000 horse-power turbine at 65 per cent. of full speed.

Above 75 per cent. of full speed and 33 per cent. of full power the 7000 horse-power turbine is distinctly more economical than the reciprocating engines of the vessels named. Mr Speekman did not think the extra consumption at low speed would outweigh the advantages of the turbine in other directions.

Going astern.—Sir William White considers too much importance had been placed on the power required with the engines reversed, as it was not possible to go astern at very high speed. In the case of the *Viper* a speed of 14 knots was made going astern: this was very high, and as the vessel was not then under control, a less proportion of power would have been sufficient for the backward motion.[1]

The Parsons Marine Steam Turbine Company fit separate high-pressure turbines, as a rule, for going astern on the same shafts which carry low-pressure turbines for forward propulsion.

Professor Rateau patented in 1898 a "go astern" turbine hidden inside the low-pressure main (*i.e.* forward) turbine without using additional space. This system was adopted in the French torpedo boat No. 243, and in the *Libellule*, etc.

Economical Steam Consumption at all Speeds.—To secure economy at all speeds a combination of reciprocating engine exhausting into turbines has been advocated and tried. Professor Rateau considers the division of power between the reciprocating engine and the turbine should be—

TABLE CXX.—DIVISION OF POWER BETWEEN RECIPROCATING ENGINE AND TURBINES IN VESSELS ADAPTED FOR ECONOMICAL RESULTS AT ALL SPEEDS.

	H.P. Reciprocating Engine.		H.P. of Turbines.
Not less than	1	to	5
And can well be	1	to	1

The Parsons Patents 367 (1897) and 16551 (1900) deal with the use of the reciprocating engine for the expansion of steam from boiler pressure, and for the further expansion of the reciprocating engine's "exhaust" the use of a low-pressure turbine. The economy in fuel per horse-power developed by the adoption of this so-called "mongrel" system is estimated[2] by the Hon. C. A. Parsons as at least 15 per cent.

Professor Rateau supplied two Rateau turbines on the two side shafts to Messrs Yarrow & Co. for the *Caroline*, which has a 250 B.H.P reciprocating engine on the centre shaft.

The First Parsons Marine Steam Turbine.—The first vessel fitted with a steam turbine was an experimental one, and it was put through thirty-one trials, with various arrangements of turbines

[1] Institution of Naval Architects, discussion, March 25th, 1904.

[2] *The Engineer*, January 8th, 1904, p. 46.

and propellers. These tests were described by the Hon. C. A. Parsons, M.A., F.R.S., before the Institution of Naval Architects, June 26th, 1903, and by permission the following details and re-

FIG. 439. — "Turbinia" (the First).

(*The Institute of Engineers and Shipbuilders of Scotland.*)

sults are reproduced, the results from the report of Professor J. A. Ewing, F.R.S., in his series of tests of the *Turbinia* in 1897, and some subsequent tests also being given.

Name of Vessel	*Turbinia.*
Date of first trial	Nov. 14, 1894.
Name of Builder	The Parsons Marine Steam Turbine Co.
Place "	Wallsend-on-Tyne.
Vessel's length	100 feet (30·5 metres).
" beam	9 " (2·7 ")
" draught	3 " (·9 ")
" displacement . . .	44½ tons.
Boiler	One double-ended water-tube type.
Heating surface	1100 sq. ft. (102·2 sq. m.).
Grate area	42 sq. ft. (3·9 sq. m.).
Condensers' surface	4200 sq. ft. (390 sq. m.).
Expansion ratio	150 fold.
Air pumps	one main and one small spare.
Circulation	by reversible scoops. When scoops not available, by small pump.
Feed pumps	one main and one spare.
Oil circulation	to shaft bearings and thrusts from one pump.

Going astern.—In the three-shaft arrangement the middle shaft was extended forward and carried a "go-astern" turbine and a fan for forced draught.

Weights :—

Boiler, 3 screws, shafting, tanks	18·35 tons.
3 turbines	3·65 ,,
Hull complete	15· ,,
Water and coal	7·5 ,,
Total displacement .	44·5 tons.

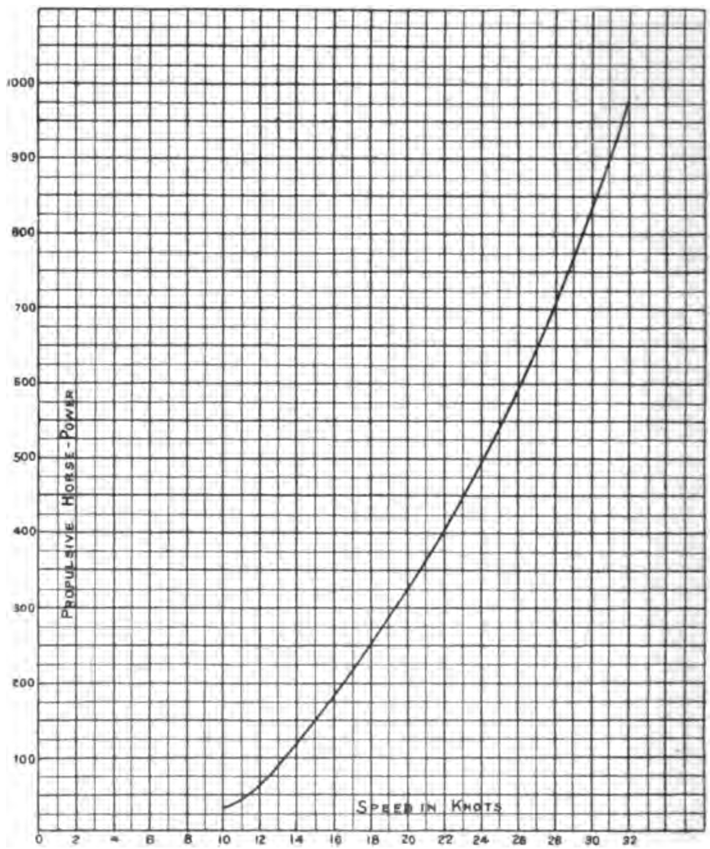


FIG. 440.—"Turbinia": P.H.P. (10 to 32 Knots).

TABLE CXXI.—SOME OF THE TESTS OF "TURBINIA" (THE FIRST).

Date of Test.	Nov. 14, 1894.		1896.	1897.	1903.
	1st Trial.			Prof. Ewing's Tests.	
Shafts number	1	1	3	same	same
Diameter	...	...	2½in.	...	...
Inclination of middle	...	...	1 in 16	...	...
„ side shafts	...	...	1 in 8½	...	...
Propellers, total number	1	3	9	...	3
Distance apart	...	3 diams.	...	...	...
Blades each	2	...	...	...	...
Diameter	30 in.	...	18in.	...	28in.
Pitch	27 in.	20in., 22in., 22in.	24in.	...	28in.
Slip middle shaft	48·8 %	37·5 %	...	17 %	...
Side shafts	...	...	...	25·5 %	...
Speed attained, knots	...	19¾	...	32·76 and 34	...
Parsons steam turbines—number	1	1	3	same	...
Type	Compound	Compound	...	...	...
High-pressure position	Amidship	Amidship	Starboard	...	...
Revolutions	...	...	2200	2230	...
Intermediate: position	...	...	Port	...	...
Revolutions	...	...	...	2230	...
Low-pressure position	...	...	Amidship	...	...
Revolutions	...	...	...	2000	...
Boiler gauge pressure	...	...	...	210 lbs.	...
Draught „	...	...	...	7in. water	...
Test results shown in Figures	...	...	...	440 to 445	446 and 447

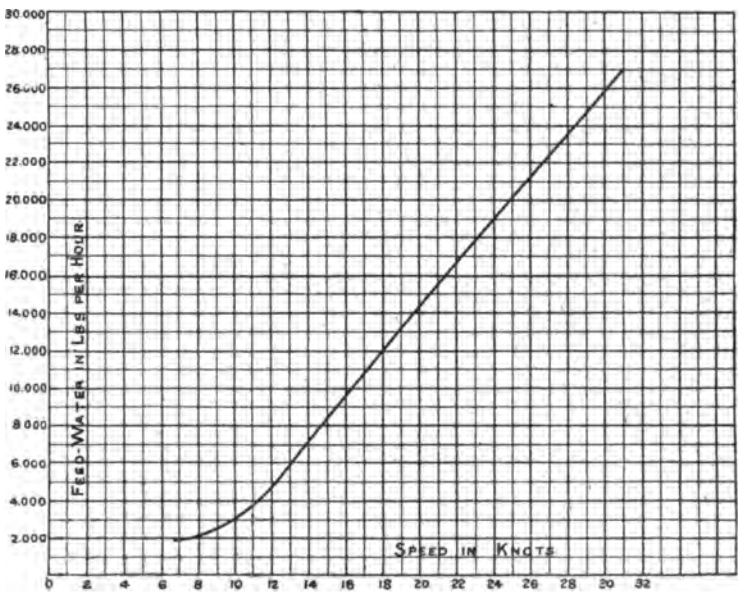


FIG. 441.—"Turbinia": Total Lbs. of Steam per Hour.

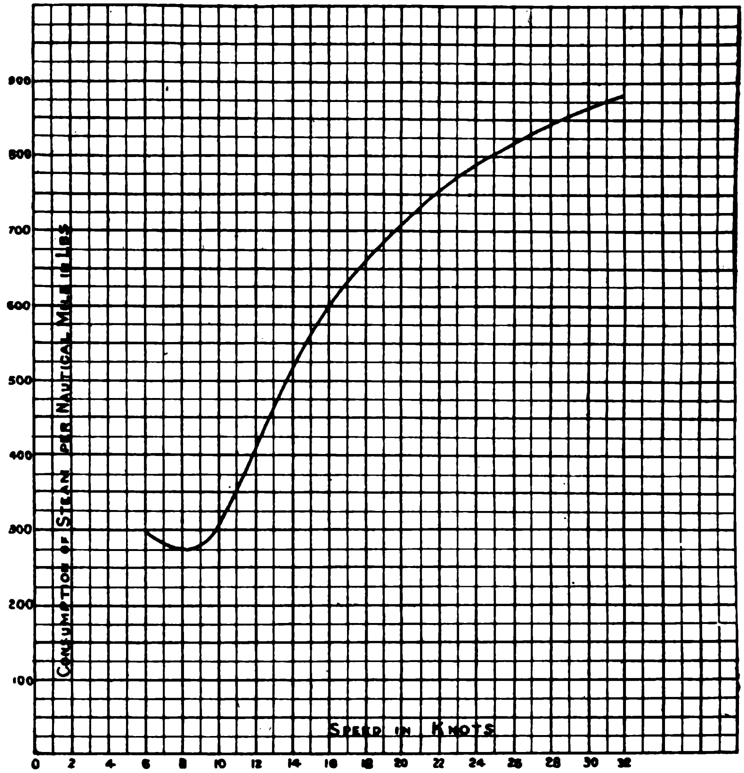


FIG. 442.—"Turbinia": Lbs. of Steam per Nautical Mile for Speeds 6 to 32 Knots.

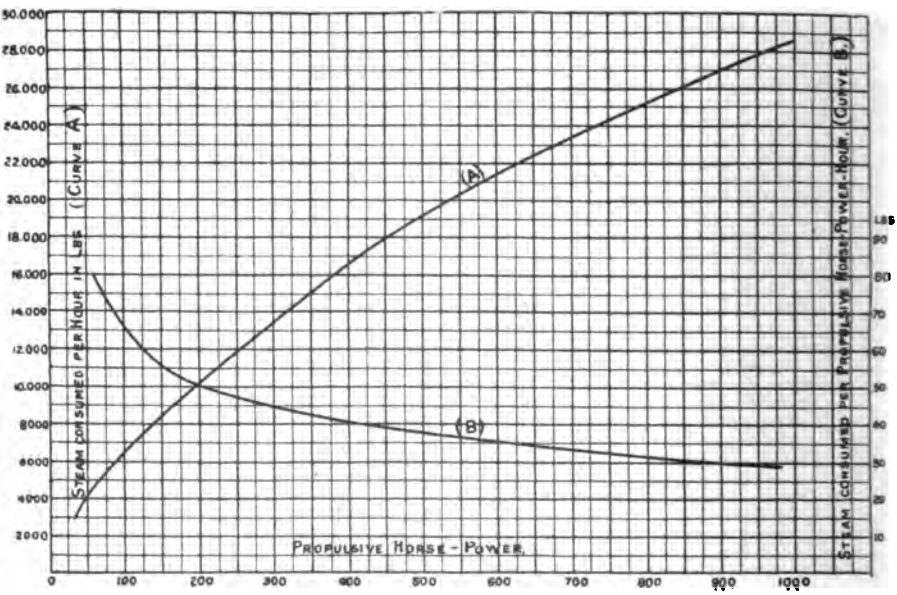


FIG. 443.—"Turbinia": Steam per Hour.

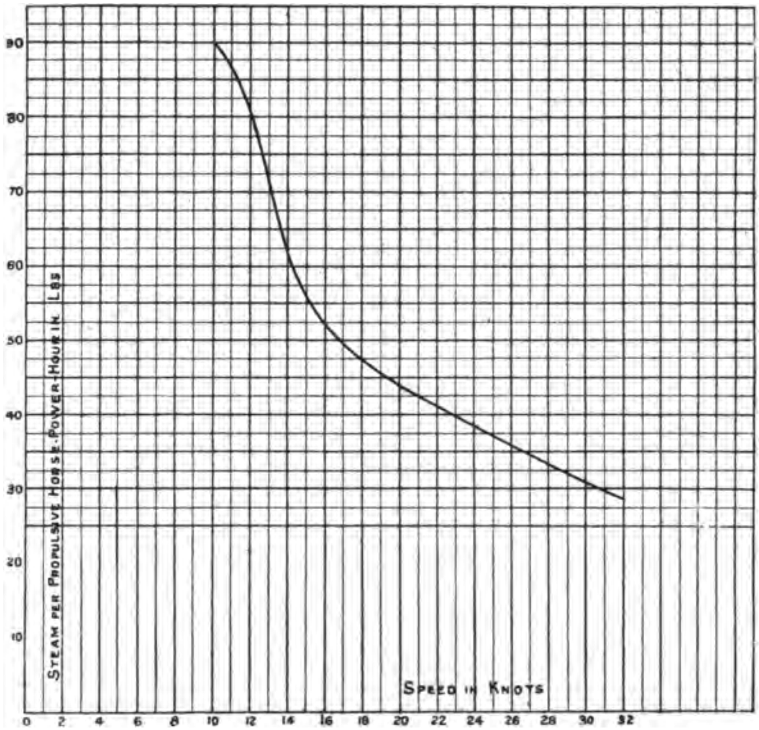


Fig. 444.—"Turbinia": Steam per P.H.P. Hour for Speeds 10 to 32 Knots.

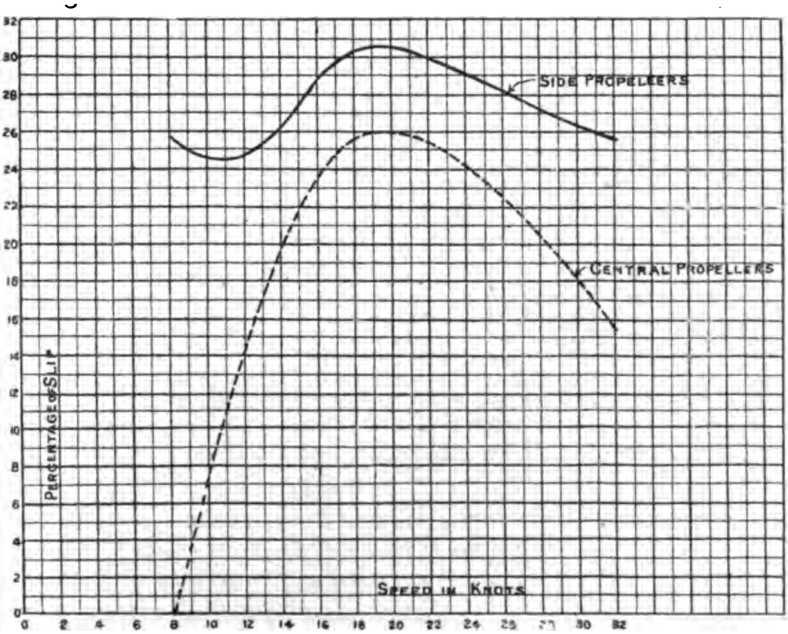


Fig. 445.—"Turbinia": Slip of Propellers.

TABLE CXXII.—RESULTS OF WATER CONSUMPTION TESTS BY PROFESSOR J. A. EWING, F.R.S. (ARRANGED IN ORDER OF SPEEDS.)

Date, 1897, April.	Speed. Knots.	Absolute Steam Pressure on Admission to H.P. Turbine. Lbs. per sq. in.	Feed Water by Meter. Lbs. per Hour.
14	6·75	8	1,950 Siemens Meter
23	6·74	8	1,930 Kent " [1]
"	9·39	12	2,760 " "
10	10·5	15	3,390 Siemens "
12	12·37	22	5,180 " "
14	14·64	38	8,300 " "
10	[17·8]	58	11,600 " "
29	18·6	...	12,600 [2]
12	[22·8]	88	17,900 Siemens Meter
21	[25·8]	107	20,650 " " [1]
9	[26·2]	108	21,900 " "
21	31·1	150	27,020 " " [1]

[1] Tests by Mr Stanley Dunkeley on behalf of Professor Ewing.
[2] Supplementary test by Mr Gerald Stoney.

From the curves of Figs. 440–1 Professor Ewing obtained the relations in Table CXXIII. between the speed, the feed water, the propulsive horse-power (P.H.P.), and the feed water per (propulsive) H.P.H. (the numbers in brackets having been obtained by producing the curves). These he plotted in Figs. 441–4, pp. 639–41.

TABLE CXXIII.

Speed in knots.	Feed Water in lbs. per hour.	Propulsive H.P.	Feed Water per P.H.P. Hour.
10	3,050	34	89·8
11	3,800	44	86·5
12	4,800	60	80·0
13	6,000	85	70·6
14	7,200	118	61·0
15	8,400	150	56·0
16	9,550	184	51·9
18	11,900	252	47·5
20	14,220	325	43·9
22	16,550	402	41·2
24	18,900	490	38·5
26	21,150	590	35·9
28	23,500	704	33·4
30	25,850	836	31·0
31	27,000	[905]	29·8
32	[28,200]	[980]	28·8

Professor Ewing's comparison of these results with those obtained in high-speed boats equipped with reciprocating engines was as follows:—

TABLE CXXIV.—STEAM CONSUMPTION OF "TURBINIA" COMPARED WITH RECIPROCATING-ENGINE VESSEL.

At Full Power.	*Turbinia.*	High-Speed Vessels in general with Recip. Engines.
Steam per I.H.P. hour	14½ lbs.[1]	18 lbs.
„ P.H.P. hour	29	30[2]
Propulsive Coefficient[3]	·5	·55 to ·6
Full Power	2100 I.H.P.	...
I.H.P. per ton of displacement	50 approx.	...
I.H.P. per ton weight of machinery	100	55

[1] $29 \times \cdot 5 = 14 \cdot 5$.

[2] $\frac{18}{\cdot 6} = 30$ (using coefficient most favourable to reciprocating engine).

[3] Ratio of propulsive horse-power to indicated horse-power.

Acceleration.—Professor Ewing started the *Turbinia* from rest, and attained a speed of rotation corresponding to 28 knots in 20 seconds after the signal was given to open the stop valve.

(This corresponds to 47·3 feet per second speed attained, *i.e.* 2·36 feet per second per second acceleration, or 1·6 miles per hour per second.)

TABLE CXXV.—"TURBINIA": APPROXIMATE COAL CONSUMPTION, APR. 23, 1897.[1]

Coal	Nixon's navigation.
Length of test	2 hrs. 29 mins.
Total coal burned	648 lbs.
Speed	9·39 knots.
Lbs. of coal per nautical mile	28
From Fig. 441.	
Feed water per hour	294 lbs.
Evaporation per lb. of coal	10·5 lbs.

[1] Professor J. A. Ewing's report stated, "with so large a grate it is difficult to avoid considerable error in estimating the state of the fire, and much reliance cannot be placed" in these figures.

In May 1903 trials were made with one propeller on each shaft instead of three on each shaft. A series of runs was first made with her earlier set of nine propellers, when it was found that the speed and steam pressure followed exactly the same curve as that obtained by Professor Ewing six years previously, proving that no deterioration had taken place in the turbines, the vessel having

undergone many trials, and having been to the Solent and back and to Paris and back in the interval. She was next run with three propellers of 28 in. diameter and 28 in. pitch, the results being shown in Figs. 446 and 447.

The single propellers show the greatest advantage at about 21 knots, where the gain amounts to 2 knots.

Cavitation.—The loss of efficiency which had been observed at certain speeds in some vessels fitted with tandem propellers on each shaft seemed to be due to interference and cavitation, and Figs. 448–450 and the description of the Hon. C. A. Parsons' experiments [1] made to demonstrate this are reproduced.

The extremely high speed, so far as marine propulsion is concerned, at which it is necessary for steam turbines to run in order to be efficient, introduces some modification of conditions in regard to the propellers. Water being a more or less viscous fluid, it is only possible for it to flow in at the back of a rotating blade of a propeller at a limited speed. If, therefore, a very high number of revolutions be adopted, there is apt to be a cavity at the back of the propeller; this naturally detracts largely from efficiency. In torpedo vessels propelled by ordinary engines the limit was previously very nearly reached, if not passed, and Mr Sydney W. Barnaby, of Chiswick, investigated this subject in connection with the Thorneycroft torpedo-boat destroyers. Mr Parsons had to deal with this difficulty in a magnified degree, and in order to get certain data on the subject he made some very interesting and ingenious experiments. Model screws, which were made to revolve with great rapidity, were placed in a bath of water brought to a temperature just short of boiling point. The immersion of the screw was proportionate to that of an actual screw working a propeller. The ratio of depth beneath the surface of the water was a necessary factor in the experiment, for it will be easily understood that the extent of the vacuum is influenced by the pressure of the water in the neighbourhood of the place where the vacuum is to be formed, and that pressure is, of course, governed by the head of water above the spot. A close resemblance in these respects to the actual working conditions of the screw being thus obtained, Mr Parsons proceeded to actually show the phenomena that occurred in the following way.

The water being near boiling point, the reduction in pressure at the back of the blades led to the formation of steam, according to the well-known law that the boiling point occurs at a lower

[1] By courtesy of the Parsons Marine Steam Turbine Co., Ld.

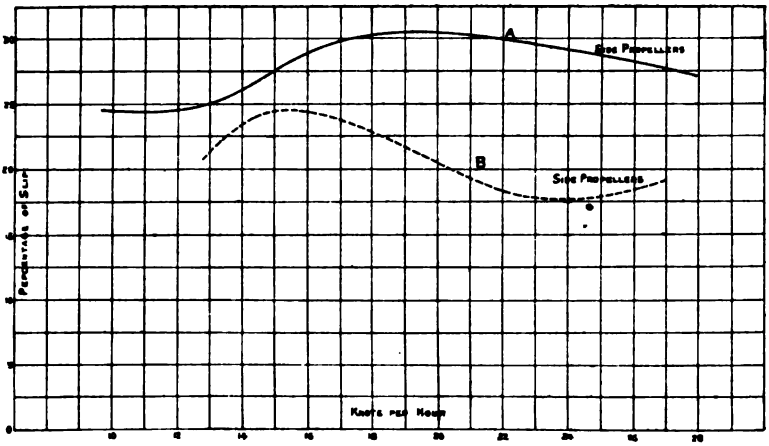


Fig. 446.

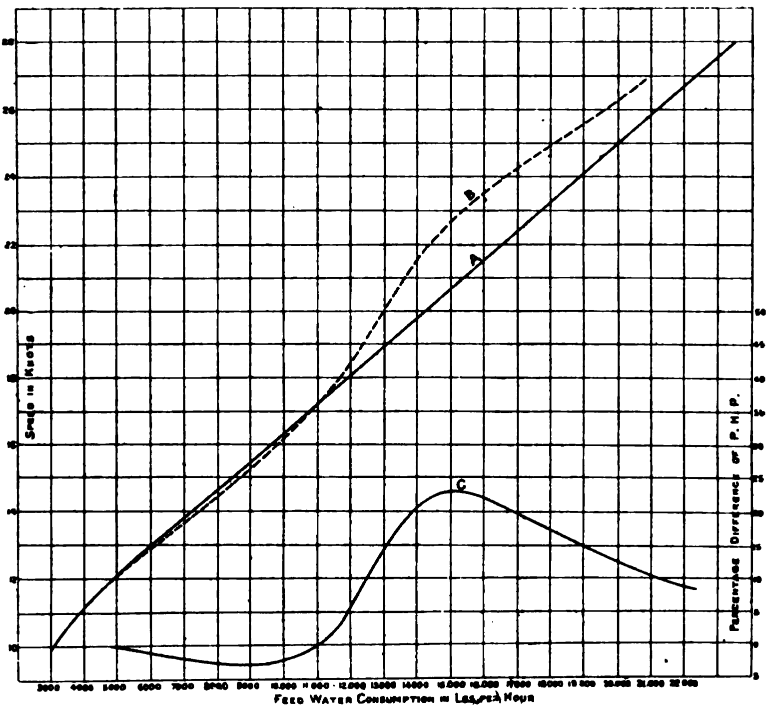


Fig. 447.

Figs. 446 and 447.—" Turbinia ": Comparison of Two Sets of Propellers. Tests May 1903.

Curve A: 3 Propellers on each of 3 Shafts.
,, B: 1 ,, ,,
,, C: Percentage Difference in P.H.P. with 3 Propellers (B) compared with 9 Propellers (A).

For same quantity of Steam per Hour the Maximum Increase in P.H.P. is 23 per cent.

temperature as pressure is reduced. Intermittent illumination of the propeller was obtained from an arc lamp by means of an ordinary lantern with condenser and mirrors. In this way the propeller was illuminated in a definite position of each revolution, the light falling on one point only, so that the shape, form, and growth of the cavities could be clearly traced, the propeller appearing stationary; the cavities about the blades could also be observed in the same way. The propeller was running at 1500 revolutions per minute, and the exposure was $\frac{1}{3000}$ of a second in duration. In Figs. 448–450 we reprint illustrations of these cavitation experiments. In describing them, Mr Parsons stated that a blister was first formed a little behind the leading edge, and near the tip of the blade; then, as the speed of revolution was increased, it enlarged in all directions, until, at a speed corresponding to that of the *Turbinia's* first and original single propeller, it had grown so as to cover a section of the screw disc, of 90°. When the speed was still further increased, the screw as a whole revolved in a cylindrical cavity, from one end of which the blade scraped off layers of solid water, delivering them to the other. In this extreme case nearly the whole energy of the screw was expended in maintaining this vacuous space. This shows that when the cavity had grown to be a little larger than the width of the blade the leading edge acted like a wedge, the forward side of the edge giving negative thrust. In Fig. 448 the high speed of 1500 revolutions of propeller per minute is shown. By the aid of these experiments Mr Parsons was able to determine the proper dimensions of a propeller and the corresponding speed of revolution. The result has been that the total efficiency of the mechanism has been greatly increased, and the high speeds attained experimentally have been reached in practice.

The speed of the latest largest turbines (for Cunard Company), it will be noted, was limited to 180 revolutions per minute.

Stopping the "Turbinia" from Full Speed.—The Hon. C. A. Parsons stated, March 19th, 1901, in reply to the discussion on his paper before the Institution of Engineers and Shipbuilders in Scotland, that the propulsive power of the *Turbinia* was one-ninth of her weight when at full speed; and when the steam was shut off, that retarding force alone (if it were continuously and uniformly maintained, and allowing for the momentum of the stream lines of the vessel) would bring her to rest in about 550 feet.

Assuming the stern turbines were put into operation as quickly as possible, he thought she would be brought to rest under 300 feet

Figs. 448, 449, and 450.—Parsons' Cavitation Experiments.

Fig. 448 (top).—1500 Revolutions per Minute.

Service . . . . British Admiralty.
Type . . . . Third Class Cruisers.

	Turbine Cruiser.	Reciprocating-Engine Cruisers.		
Name of Vessel . . .	"Amethyst."	*Topaze.*	*Sapphire.*	*Diamond.*
Keel laid	...	*Aug. 14, 1902*	...	...
Date of launch . . .	Nov. 5, 1903	...	...	...
Date of trials . . .	Nov. 1904.	*Nov. 1904*	...	...
Name of builder . .	Armstrong, Whitworth & Co.	*Cammell, Laird & Co.*	*Palmers, S. & I. Co.*	*Cammell, Laird & Co.*
Place	Elswick	*Birkenhead*	...	*Birkenhead*
Vessel's length over all .	360ft.	*360ft.*	*360ft.*	*360ft.*
Length between perpendicular	...	...	...	...
Breadth moulded . .	39ft. 10½in.	*39 ft. 10½ in.*	*39ft. 10½in.*	*30ft. 10½in.*
Beam	40ft.	*40 ft.*	*40 ft.*	*40ft.*
Beam, including rolling chocks	...	...	...	...
Moulded depth (amidships)	21ft. 8in.	*21ft. 8in.*	*21ft. 8in.*	*21ft. 8in.*
Depth, upper deck to keel.	...	...	...	...
Depth, promenade deck to keel	...	...	...	...
Draught—mean . .	14ft. 6in.	*14ft. 6in.*	*14ft. 6in.*	*14ft. 6in.*
Armament . . .	12-4in. Q.F. 8-3 pounder Q.F. guns 2 Maxims 2-18in. torpedo tubes above water	*12-4in. Q.F. 8-3 pounder Q.F. guns 2 Maxims 2-18in. torpedo tubes above water*	*12-4in. Q.F. 8-3 pounder Q.F. guns 2 Maxims 2 18in. torpedo tubes above water*	*12-4in. Q.F. 8-3 pounder Q.F. guns 2 Maxims 2-18in. torpedo tubes above water*
Displacement . . .	3009 tons	*3009*	*3009 tons*	*3009 tons*
Protection, conning tower .	3in.	*3in.*	*3 in.*	*3in.*
Protective deck over machinery spaces	flat 1in., slopes 2in.	*flat 1in., slopes 2in.*	*flat 1in., slopes 2in.*	*flat 1in., slopes 2in.*
Protective deck at ends .	flat 0·75in., slopes 1in.	*flat 0·75in., slopes 1in.*	*flat 0·75in., slopes 1in.*	*flat 0·75 in. slopes 1in.*
Speed (forward) . .	*23·63* knots	*22·34 knots*	...	...
Speed (astern) . . .	...	...	...	...
Radius of action at 20 knots, 760 tons	3160	*2140*	...	...
Normal coal, 300 tons .	...	...	...	...
Average running speed .	...	...	...	...
Time to stop from full speed ahead	7½ to 20 secs.	...	...	...
Horse-power . . .	9800	*9800*	...	...
Boilers:—				
Maker	Hawthorn, Leslie, & Co.	*Laird - Normand*	*Reed*	*Laird-Normand*
Type	Modified Yarrow water tube	*water tube*	...	...
Number installed . .	10 single ended	*10 single ended*	*10 single ended*	*10 single ended*
Tube diameter . .	1⅛in. and 1⅜in. (2 rows)	*1$\frac{5}{16}$in. and 1$\frac{9}{16}$in.*	*1$\frac{1}{16}$in. and 1$\frac{5}{16}$in.*	*1$\frac{5}{16}$in. and 1$\frac{9}{16}$in.*
Rated capacity (lbs. per hour)	...	...	...	...
Heating surface, sq. ft. .	25,968	*26,000*	*26,010*	...
Grate area	493½	...	...	...
Draught pressure (water)	1·6in. to 1·7in.	*1·7in. to 2·6in.*	...	...

	Turbine Cruiser.	Reciprocating-Engine Cruisers.		
Name of Vessel . . .	"Amethyst."	*Topaze.*	*Sapphire.*	*Diamond.*
Draught pressure produced by	enclosed steam engine	*enclosed steam engine*	*enclosed steam engine*	*enclosed steam engine*
Steam pressure . .	...	...	...	...
Funnels:—				
Number. . . .	3	...	...	...
Diameter . . .	...	...	...	...
Superheaters . . .	none	...	...	...
Shafts:—				
Number . . .	3	*2*	*2*	...
Diameter . . .	...	...	...	...
Weight	...	..	...	..
Propellers per shaft . .	1	*1*	*1*	...
Number of blades each .	3	*4*	*3*	...
Diameters all . . .	6ft. 8in.	..	...	...
.	Two Centre sides	...	...	...
Pitch in feet . . .	6·56 5·75	...	...	...
Area sq. ft. . . .	19·64 19·48	...	...	.
Steam turbine:—				
Made by . . .	Parsons Marine Steam Turbine Co.	...	...	...
Type	...			
Number . . .	9	...	...	...
Height	20ins. less than *Topaze* reciprocating engines.	...	...	...
Total Weight . . .	practically equal	...	...	...
Cruising Turbines:—				
Number . . .	2 high, 2 intermediate.	...	...	..
Position	forward end of port and starboard shafts.	...	...	..
High-pressure, diameter of drum	44in.	...	..	...
Intermediate - pressure, diameter of drum	44in. special blades	...	...	...
Main high-pressure Turbine:—				
Number . . .	1	...	...	...
Diameter of drum . . .	60in.	...	...	...
Position	centre shaft	...	...	...
Revolutions . . .	see Table CXXVI.	see Table CXXVIII.	...	...
Low-pressure Turbine:—				
Number	2	...	...	...
Position	port and starboard shafts	...	...	...
Diameter of drum . .	60in., drum longer and different blades	...	...	...
Go-astern Turbines:—				
Number	2	...	...	..
Position	port and starboard shafts	...	...	.. .
Revolutions . .	...	..	...	...

Course of Steam when Cruising up to 14 knots.

Steam enters high-pressure cruising turbine.
Thence intermediate cruising turbine.
„ main high-press. turbine.
„ main low-press. turbine.
„ condenser.

At 18 and 20 knots the steam first enters the intermediate cruising turbine, the high-pressure cruising turbine being out of service.

At full speed the cruising turbines are both out of service.

For Comparison.—Reciprocating Engines in other Vessels.

	Turbine Cruiser.	Reciprocating-Engine Cruisers.		
Name of Vessel . . .	"Amethyst."	*Topaze.*	*Sapphire.*	*Diamond.*
Piston Engines:—				
Maker	...	*Palmers, S. & I. Co.*	*Cammell, Laird & Co., Birkenhead.*	*Cammell, Laird & Co., Birkenhead.*
Type	...	...	...	...
Number . . .	...	...	...	...
Cylinders, diameters .	...	*24¼in., 38½in. 42¼in., 42½ in.*	...	...
Revolutions per minute, full speed	...	*250*	.	..
Stroke	...	*24in.*	...	...
Rated power, condensing	...	...	...	...
Rated power, non-condensing	...	...	...	...
Comparative Steam Consumption.	See Tables CXXVI. and CXXVII.	...	...	...
Llbs. per hour of steam at 20 knots	70 per cent	*100 per cent.*	...	...
Lbs. per hour of steam at 18 knots	80 per cent.	*100 per cent.*	...	...
Lbs. per hour of steam at 14 knots	approx. 100 per cent.	*100 per cent.*	..	...
Lbs. per hour of steam at 10 knots	123 per cent.	*100 per cent.*	...	...
Exhaust[1] steam from auxiliary engines on "Amethyst" passed to .	condenser	*l.p. receiver*	...	...
Coal burned per hour, full speed	See Table . 90 per cent.	*100 per cent.*	...	...
Condenser:—				
Made by	...	...	...	...
Type	Main condensers but no "augmenters"	...	...	...
Number	...	...	...	...
Surface	...	...	...	...

[1] This gives the reciprocating engines an advantage.

	Turbine Cruiser.	Reciprocating-Engine Cruisers.		
Name of Vessel . . .	"**Amethyst.**"	*Topaze.*	*Sapphire.*	*Diamond.*
Air pump:—				
Maker	Weir	...	...	...
Type	...	*off main engines*	...	...
Vacuum maintained at full speed	...	...	...	...
Temperature of discharge at full speed	...	...	...	..
Steam per hour used at full speed	...	...	...	...
Air pump barrel diameter and stroke	...	...	...	...
Steam cylinder—diameter	...	...	...	...
Strokes per minute . .	...	...	. .	...
Circulating pump:—				
Made by . . .	..	...	...	...
Type	...	...	...	...
Steam per hour at full speed	...	...	...	...
Weight of circulating water per unit weight of steam	...	...	...	...
Temperature suction .	...	...	...	...
Temperature discharge .	...	...	...	...
Electric-lighting engine .	Two reciprocating engines	*Two reciprocating engines*	*Two reciprocating engines*	*Two reciprocating engines*
Maker	...	...	...	...
Type	Forced lubrication	...	...	...
K.W. capacity each .	350 amps. 150 volts	...	...	...
Position	...	...	...	..
Illustration of vessel . .	Fig. 451	...	...	...
Feed pumps:—				
Made by	...	...	...	...
Type	...	...	...	...
Number	1 main, 2 auxiliary	...	...	...
Water cylinder, diameter stroke	...	...	..	...
Steam cylinder, diameter	...	...	...	...
Capacity per hour	...	...	...	...
Steam consumed per hour	...	...	...	...
Oil circulation	2 Weir pumps	...	..	. .
Steam consumed per hour	...	...	...	...
Weights of machinery .	535 tons	*537 tons*	...	..
Assuming I.H.P. of Turbines	14,000	...	...	...
At speed knots . .	23·63	...	...	...
I.H.P. per ton of machinery	26	*18·3*	...	..
Costs	...	...	...	...
Test Results . . .	See Table CXXVI. from *Engineering*. See curves, Figs. 453–5	...	...	...

TABLE CXXVI.—RESULTS OF STEAM TRIALS OF H.M.S. "AMETHYST" WITH PARSONS' STEAM TURBINES.

Speed of ship		10 knots	14·062 knots.	18·186 knots	20·6 knots	23·06 knots	23·63 knots
Date of trial 1904		October 19 and 20	October 24 and 25	October 31 and Nov. 1	November 4	November 8	November 16
Duration of trial		24 hours	24 hours	30 hours	8 hours	4 hours	4 hours
Draught of water (mean)		14ft. 7in.	14ft. 7in.	14ft. 6in.	14ft. 8in.	14ft. 7in.	14ft. 6in.
Number of boilers in use		4	...	...	...	...	...
Air pressure in stokeholds		0·2in.	0·3in.	0·45in.	0·46in.	1·7in.	1·6in.
Steam pressure in boilers		259lb.	263lb.	246lb.	255·2lb.	243·7lb.	260·6lb.
Steam pressure in receivers	Cruising H.P.	94 „	216 „	...	...	...	...
	„ I.P.	19 „	61·2 „	137·5lb.	190·6lb.	...	...
	Main H.P.	2·7 „	18 „	53·7 „	75·6 „	158·3lb.	174·3lb.
	„ star L.P.	Vac. 21·7in.	Vac. 10·8in.	1·3 „	6·1 „	23·5 „	27·3 „
	„ port L.P.	„ 19·9 „	„ 11·8 „	Vac. 1·3in.	4·8 „	24·6 „	27·3 „
Vacuum in condensers	Starboard	26in.	27in.	26·6in.	27·8in.	26·9in.	26·5in.
	Port	26·7 „	26 „	27·6 „	27·8 „	27·0 „	27·4 „
Revolutions	Centre	167·2	237·4	319·8	361·1	436	449·4
	Starboard	198·2	289·7	391·6	450·8	488·8	484
	Port	204·2	290·5	348·1	402·1	492·9	499
Consumption of water per hour		26,260lb.	44·090lb.	76,493lb.	100,606lb.	176,845lb.	190,525lb.
„ coal per hour		2,893 „	4,725 „	8,372 „	10,937 „	24,035 „	24,412 „

TABLE CXXVII.—*Results of Steam Trials of H.M.S. "Topaze" with Reciprocating Engines.*

Speed of vessel	knots	10·058		14·08		18·1		18·069		20·063		22·103		21·826	
Date of trial, 1904		August 1 and 2		August 2 and 3		July 12 and 13		August 7 and 8		August 10		July 28		August 13	
Duration of trial 1904		24 hours		24 hours		30 hours		30 hours		8 hours		4 hours at full power		4 hours	
Steam pressure in boilers,	lb. per sq. in.	200		198		240		250		250		271		276	
Number of boilers in use		4		6		8		8		10		10		10	
Air pressure in boiler rooms,	in.	0·2		0·28		1·19		0·87		0·83		1·8		2·04	
Vacuum — Starboard	,,	25·7		26·0		24·8		25·7		25·2		24·0		25·3	
Vacuum — Port	,,	25·3		25·0		24·0		24·8		24·4		24·0		23·8	
Revolutions — Starboard		107·5		150·7		198·6		195·7		219·6		245·6		242·8	
Revolutions — Port		106·5		150·3		196·8		195·7		219·2		945·5		243·8	
Revolutions — Mean		107·0		150·5		197·7		195·7		219·4		245·55		243·3	
		Starboard	Port	Starboard	Port	Starboard	Port	Starboard	Port	Starboard	Port	Starboard	Port	Starboard	Port
Mean pressure in receivers — High	lbs.	75	74	142	150	192	190	188	190	216	214	244	245	240	237
Mean pressure in receivers — Intermediate	,,	13·6	13·9	39	46	59	60	59	61	74	76	89·6	29·4	89	96·5
Mean pressure in receivers — Low	,,	3·6in. vac.	5·2in. vac.	2·8	4·2	12	13·8	8·7	10·6	14	15	22·2	23·1	22·5	23·9
Mean pressure in cylinders — High	,,	20·82	20·88	38·57	34·63	74	62	64·6	61·8	80	80	115	111	102·6	94·5
Mean pressure in cylinders — Intermediate	,,	6·94	7·0	15·57	15·15	26·1	28·4	26·7	27·3	34·2	36·6	44·5	47·2	44	49·9
Mean pressure in cylinders — Low forward	,,	6·34	6·07	9·25	10·36	13·8	15·2	13·29	15·04	16·7	17·26	20·1	21·5	20·7	22·84
Mean pressure in cylinders — Low aft	,,	5·69	5·82	8·99	9·75	13·8	15·5	13·55	15·37	16·61	17·35	21·5	22·7	21·46	23·6
Mean indicated horse-power — High		125	125	326	292	821	684	706	678	983	982	1585	1534	1395	1292
Mean indicated horse-power — Intermediate		106	105	331	321	733	790	735	755	1058	1132	1541	1637	1508	1716
Mean indicated horse-power — Low forward		116	110	237	265	466	511	441	501	623	644	841	897	853	946
Mean indicated horse-power — Low aft		104	106	230	249	467	521	449	511	620	647	897	946	885	978
Indicated horse-power		897		2251		4,493		4,776		6,689		9,868		9,573	
Consumption of coal per hour	lbs.	2296		4640		10,484		10,900		15,451		26,150		27,700	
Consumption of coal per indicated H.P.H.	,,	2·56		2·06		2·3		2·28		2·31		2·65		2·89	
Consumption of water per indicated H.P.H.	,,	23·74		18·77		19·0		18·95		20·07		20·18		21·93	
Consumption of water per hour	,,	21,294		42,260		94,867		90,500		134,248		199,140		209,950	

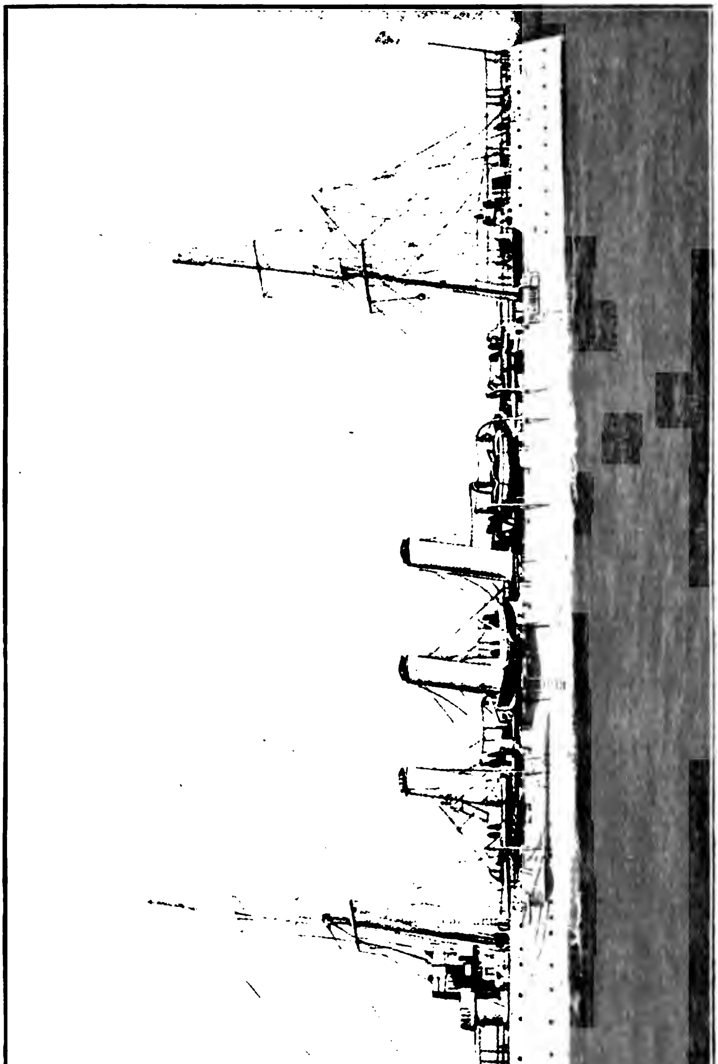


FIG. 451.—H.M.S. "Amethyst," Protected Cruiser. (*Messrs Armstrong, Whitworth & Co., Ltd.*)

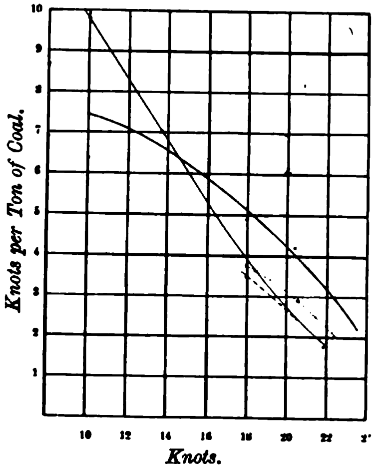


FIG. 452.

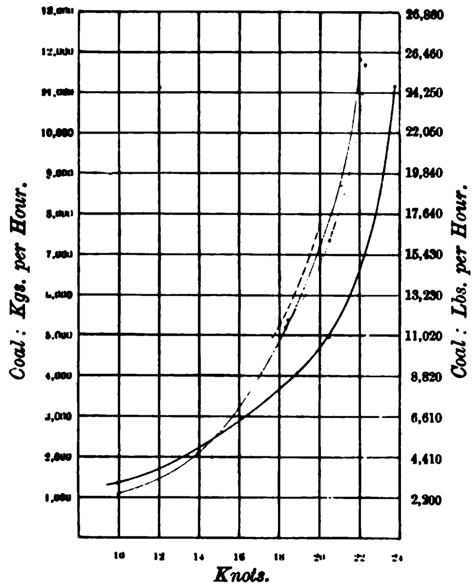


FIG. 453.

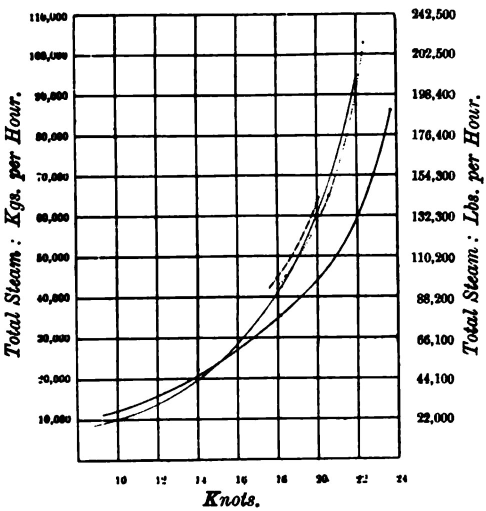


FIG. 454.

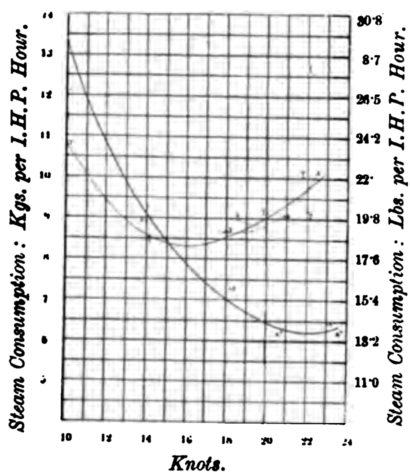


FIG. 455.

FIGS. 452 to 455.—Steam and Coal Consumption of British Cruisers : Turbines *versus* Reciprocating Engines.

Full heavy line—**Amethyst.** Dotted line—*Sapphire.*
Full light line—*Topaze.* Broken and dotted line—*Diamond.*

(*Turbinia Deutsche Parsons Marine A.G.*)

TABLE CXXVIII.—COMPARISON OF TOTAL STEAM CONSUMPTION.

	"Amethyst."	*Topaze.*	*Sapphire.*	*Diamond.*
24 Hours' Trial at 10 *Knots.*				
I.H.P. (Indicated horse-power)	897[1]	*897*	...	...
Speed in knots	10	*10·05*	...	...
Total water per hour in lbs.	26,260	*21,294*	...	...
Water for auxiliary—lbs. per hour	...	*4,538*	...	...
Water for auxiliary—per cent. of total	...	*21 per cent.*	...	...
Water per I.H.P. hour	29·3 lbs.	*23·74 lbs.*	...	...
24 Hours' Trial at 14 *Knots.*				
I.H.P.	2,250[1]	*2,251*	..	...
Speed in knots	14·06	*14,08*	...	...
Total water per hour in lbs.	44,090	*42,260*	...	...
Water for auxiliaries—lbs. per hour	...	*5,672*	...	...
Water for auxiliaries—per cent of total	...	*13 per cent.*	...	...
Water per I.H.P. hour	19·6 lbs.	*18·77 lbs.*	...	...
30 Hours' Trial at 18 *Knots.*				
I.H.P.	4,770[1]	*4,776*	*5,012*	*5,074*
Speed in knots	18·186	*18·069*	*18·47*	*18*
Total water per hour in lbs.	76,493	*90,500*	*99,200*	*96,410*
Water per I.H.P. hour	16	*18·95*	*19·8*	*19*
8 Hours' Trial at 20 *Knots.*				
I.H.P.	7,230[1]	*6,689*	*7,281*	*7,145*
Speed in knots	20·6	*20·063*	*20·68*	*20*
Total water per hour in lbs.	100,606	*134,248*	*144,160*	*137,930*
Water per I.H.P. hour	13·8 lbs.	*20·07 lbs.*	*19·8 lbs.*	*19·31 lbs.*

	"Amethyst."		*Topaze.*		*Sapphire.*
4 Hours' Trial at Full Power.					
I.H.P.	18,000[1]	14,000[1]	*9,573*	*9,868*	*10,200*
Speed—knots	23·06	23·63	*21·826*	*22·103*	*22·34*
Total water per hour	176,845 lbs.	190,525 lbs.	*209,950 lbs.*	*199,140 lbs.*	*226,440 lbs.*
Water per I.H.P. hour	13·6 lbs.	13·6 lbs.	*21·93 lbs.*	*20·18 lbs.*	*22·2 lbs*

[1] The Indicated Horse-power of the Steam Turbine Vessel is equal to that of the *duplicate* vessels.

It is clear from Figs. 452–5 that the turbines of the **Amethyst** are more economical than the reciprocating engines of the duplicate cruisers for speeds above 15 knots, and less economical below 15 knots.

Warships steam at cruising speed for 90 per cent. to 95 per cent. of the time they are in service.

TABLE CXXIX.—COMPARISONS OF COAL CONSUMED BY DUPLICATE CRUISERS—TURBINES *versus* RECIPROCATING ENGINES.

Type of Engines.	Turbines.	*Reciprocating.*		
	"Amethyst."	*Topaze.*	*Sapphire.*	*Diamond.*
24 *Hours' Trial at* 10 *Knots.*				
Indicated horse-power	897 [1]	*897*	...	...
Total coal burnt	31 tons	*24·6 tons*	...	...
Total burnt per hour	2893 lbs.	*2296 lbs.*	...	...
Total burnt per hour per I.H.P.	3·22 ,,	*2·56* ,,	...	...
Evaporation per pound of coal	9·1 ,,	*9·3* ,,	...	...
Miles run per ton of coal	7·42	*9·75*	...	...
24 *Hours at* 14 *Knots.*				
Indicated horse-power	2250 [1]	*2251*	...	...
Total burnt	50·63 tons	*49·7 tons*	...	...
Total burnt per hour	4725 lbs.	*4640 lbs.*	...	...
Total burnt per I.H.P. per hour	2·1 ,,	*2·06* ,,	...	...
Evaporation per pound of coal	9·35 ,,	*9·13* ,,	...	...
Miles run per ton of coal	6·6	*6·8*	...	...
30 *Hours at* 18 *Knots.*				
Indicated horse-power	4770 [1]	*4776*	*5012*	*5074*
Total coal burnt	112·13 tons	*146 tons*	*157 tons*	*154·3 tons*
,, ,, per hour	8372 lbs.	*10,900 lbs.*	*11,720 lbs.*	*11,520 lbs.*
,, ,, ,, per I.H.P.	175 ,,	*2·28* ,,	*2·338* ,,	*2·27* ,,
Evaporation per pound of coal	915 ,,	*8·3* ,,	*8·45* ,,	*8·35* ,,
Miles run per ton of coal	4·8	*3·7*	*3·53* ,,	*3·5*
8 *Hours at* 20 *Knots.*				
Indicated horse-power	7280 [1]	*6689*	*7281*	*7145*
Total burnt	39·06 tons	*55·2 tons*	*57·65 tons*	*59·1 tons*
,, ,, per hour	10,937 lbs.	*15,451 lbs.*	*16·142 lbs.*	*16,570 lbs.*
,, ,, ,, per I.H.P.	1·5 ,,	*2·31* ,,	*2·217* ,,	*2·32* ,,
Evaporation per pound of coal	9·7 ,,	*8·7* ,,	*8·94* ,,	*8·34*
Miles run per ton of coal	4·22	*2·9*	*2·86*	*2·7*
4 *Hours at Full Power.*				
Indicated horse-power	13,000 14,000	*9573* *9868*	*10,200*	...
Total coal burnt—tons	42·9 43·6	*49·5* *46·6*	*45·87*	...
,, ,, per hour—lbs.	24,035 24,412	*27,700* *26,130*	*25,688*	...
,, ,, ,, per I.H.P.—lbs.	1·85 1·74	*2·89* *2·65*	*2·52*	...
Evaporation per pound of coal—lbs.	7·35 7·8	*7·56* *7·95*	*8·75*	...
Miles run per ton of coal	2·15 2·17	*1·76* *1·9*	*1·95*	...

[1] The power in the case of the *Amethyst* is, of course, assumed; the form of the ship is identical in all cases.

TABLE CXXX.—COMPARATIVE STEAM CONSUMPTION FROM THE FULL LINE CURVES OF FIG. 454, STATED IN PERCENTAGES, ARE—

At 10 knots *Topaze* uses 19 per cent. less than *Amethyst.*
15 „ „ same as *Amethyst.*
16 knots *Amethyst* uses 6 per cent. less than *Topaze.*
18 „ „ 17 „ „
20 „ „ 21 „ „
21 „ „ 33 „ „
22 „ „ 36 „ „

TABLE CXXXI.—COMPARISON OF TOTAL STEAM OF "AMETHYST" AND MAIN ENGINES STEAM OF "TOPAZE."

Lbs. per I.H.P. Hour.

	Mechanical Engineers Research Committee Trials.	"Amethyst" Turbines including Auxiliaries.	*"Topaze" Main Reciprocating Engines, excluding Auxiliaries.*
Main consideration.	Economy in Steam.	Speed for Minimum Weight.	*Speed for Minimum Weight.*
14 knots	...	...	*16·25*
18 „	...	16	*15·45*
20 „	13·35	13·8	*16·91*

TABLE CXXXII.—SLIP OF "AMETHYST'S" PROPELLERS AT DIFFERENT SPEEDS (MEAN OF THREE PROPELLERS).

10 knots	11·3 per cent.
14 „	13·6 „
18 „	13·6 „
20 „	14·4 „
23·06 very heavy weather . .	18·4 „
23·63 smooth sea	17·1 „

TABLE CXXXIII.—RADIUS OF ACTION OF "**Amethyst**" COMPARED WITH *Topaze. Coal capacity* 750 *tons each vessel.*

Type of Engine.	"Amethyst" Parsons Turbines.		*"Topaze." Reciprocating.*	
Speed knots	Radius N.M.	Advantage.	*Radius N.M.*	*Advantage*
10	5570	negative	*7300*	*31 per cent.*
14	4950	„	*5100*	*3 per cent.*
18	3600	30 per cent.	*2770*	*negative*
20	3160	47 „	*2140*	„
22	...	...	*1420*	„
23·63	1620	7·4 per cent. speed 14 „ radius		

Service . . . . The British Admiralty.
Type . . . . Torpedo Boat Destroyers.

Names of Vessels . .	"Viper."[1]	"Cobra."[2]	"Velox."	"Eden."	*30 Knots Reciprocating Engine.*
Built in year . . .	1898	1899	1902, Turbine and *reciprocating.*	1903	...
Date of launch . .	...	...	...	Mar. 14/03	...
Name of builder . .	Hawthorn, Leslie & Co.	Armstrong, Whitworth & Co., Ltd.	Hawthorn, Leslie & Co.	Hawthorn, Leslie & Co.	...
Place	...	...	...	...	...
Vessel's length overall .	210ft.	223½ft.	210ft.	220ft.	*210ft.*
Beam	21ft.	20½ft.	21ft.	23½ft.	*21ft.*
Moulded Depth . .	12½ft.	13½ft.	12½ft.	14¼ft.	...
Draught	6¾ft.	7¼ft.	7¼ft.	8¼ft.	...
Displacement . . .	370 tons	430 tons	440 tons	565 tons	*310 tons*
Speed forward . .	37·1 knots	34·6 knots	33·12 knots	26·3 knots	*30 knots*
Speed astern . . .	15·5 knots	...	...	...	...
Radius of action at . .	knots	...	...	...	...
Average running speed .	...	...	27·1 knots	...	...
Horse-power	12,300	...	9000[3]	7500	*6000/6500*
I.H.P. per ton weight of machinery, including boiler in working order	70	...	...	...	*55*
Boilers—	...	...	...	...	...
Type	Yarrow	Yarrow	Yarrow	Yarrow	...
Maker	Hawthorn, Leslie & Co.	Hawthorn, Leslie & Co.	...	Hawthorn, Leslie & Co.	...
Number installed .	...	...	...	...	...
Rated capacity (lbs. per hour)	...	...	...	...	...
Heating surface, total	15,000 sq. ft.	15,000 sq. ft.	...	...	...
Grate area	272 sq. ft.	272 sq. ft.	...	...	...
Draught pressure (water)	4½in.	...	3·1in.	...	...
Steam pressure (lbs. per sq. in.)	240	240	200	250	..
Funnels number . .	3	...	3	...	...
Diameter . . .	...	...	...	...	...
Superheaters, none . .	...	...	...	...	...
Shafts number . . .	4	4	4	3	...
Diameter	...	...	...	...	...
Weight	...	...	...	...	...
Propellers, total . .	8	8 later 12	4	6	...
Number of blades each .	...	...	...	...	...
Diameter	40in.	...	48in.	39in.	...
Steam Turbine :—					
Made by	Parsons	Parsons	Parsons	Parsons	...
Type	...	similar size and power to *Viper's*	also reciprocating in same vessel		
Cruising Turbines . .	...	...	...	2 on each side shaft	...
Number	...	...	...	...	...
Position	...	...	...	...	...

[1] Lost off Channel Islands. She ran on a rock in a fog.
[2] Lost on her voyage from the Tyne.
[3] From *Turbinia*, Deutsche Parsons Marine A.G. No. 59. Table CXXXIV. shows 12,800 I.H.P. max.

Names of Vessels	"Viper."	"Cobra."	"Velox."	"Eden."	*30 Knots Reciprocating Engines.*
High-pressure Turbines	...	...	...	...	...
Number	2[1]	2[1]	2	1	...
Position	outer shafts.	outer shafts	...	centre	...
Revolutions per minute	1180	1050	840	940	...
Low-pressure Turbines	...	...	...	...	...
Number	2	2	2	2	...
Position	inner shafts	inner shafts	...	each side shaft	...
Revolutions per minute	1180	1050	...	...	...
Go-astern Turbines	...	...	...	...	...
Number	2	2	...	2	...
Position	inner shafts	inner shafts	...	outer shafts	...
Revolutions per minute	...	...	...	...	...
Rated horse-power condensing	13,000	...	...	...	...
Rated horse-power non-condensing	...	...	...	...	...
Piston engines I.H.P. each	...	...	150	...	...
Maker	...	...	...	...	...
Type	...	...	triple expansion	...	...
Number	...	...	2	...	...
Cylinders' diameters	...	...	7½, 11, 16in.	...	...
Revolutions per minute full speed	...	...	490	...	...
Connected to l.p. Turbine shaft by	...	...	Detachable claw coupling	...	...
Stroke	...	...	9ins.	...	...
Rated power condensing	...	...	150	...	...
Rated power non-condensing	...	...	...	...	...
Steam consumed	...	...	...	...	...
Weight of steam per hour full speed	...	...	...	...	...
Coal burned per I.H.P. hour at speed	31 knots, 2·38lbs.	...	31 knots, 2·3 lbs. 27 knots, 2·5 lbs.	...	..
Coal burned total per hour	...	...	27·1 knots, 7·35 tons 11¼ knots, 8·5 *cwt.* per hour.	26·2 knots 7·45 tons	*See Table CXXXVI., p. 663.*
Condenser:—					
Made by					
Type					
Number					
Surface, sq. ft.	8000	8000	...	...	...
Surface of augmenter	none	...	...	..	..
Illustrations of vessel	Fig. 456		Fig 457		
Guaranteed Speed knots	31	...	...	25½	...
From preliminary experiments	...	...	...	...	...
Steam per I.H.P. hour	15½lbs.	...	...	...	...
Propulsive coefficient, *i.e.* ratio of propulsive H.P. to I.H.P.	55 per cent.	...	...	...	...

[1] Starboard turbines were independent of Port turbines in "Viper" and in "Cobra."

TABLE CXXXIV.—H.M.S. "VELOX" TRIALS.

Mean speed 1 hour at full power	36·58 knots
Fastest pair of runs, mean	36·87 „
Mean revolutions per minute	1180
Forced draught (water gauge)	4¼ inches
Fastest run	37·113
„ represented	12,300 I.H.P.

FIG. 456.—H.M.S. "Viper."
(*The Inst. of Engrs. and Shipbuilders of Scotland.*)

TABLE CXXXV.—H.M.S. "VELOX."[1]

Taking-over Trials on River Tyne.

Full power, mean speed	27·07 knots.
Coal consumed	9·82 tons per hour.[2]
Steam pressure	200 lbs. per sq. in.
Boilers in use	4
R.P.M. of turbines	840
Vacuum	27 inches of mercury.

Coal Consumption Trial of Reciprocating Engine.

Duration of trial	12 hours.
Speed	11·26 knots.
Coal consumed	8·58 cwts. per hour.
Steam pressure	212 lbs. per sq. in.
R.P.M. of engines	351·4.
Vacuum	28·25 inches of mercury.

[1] *The Engineer*, p. 241, March 6, 1903.
[2] *The Engineer*, p. 39, July 8, 1904, gave 7·35 tons per hour at 27·1 knots.

Recent Torpedo-Boat Destroyers.[1]—For comparisons, we give below a return made to an "order of the Honourable the

[1] *The Engineer*, supplemented by data on coal, by courtesy of the builders of destroyers built and launched between January 1st, 1902, and July 1904.

FIG. 457.—H.M.S. Torpedo-Boat Destroyer "Velox." Driven by Turbines and Reciprocating Engines. Length 210 Feet; 33 Knots; 9000 Horse-Power.

House of Commons." With the exception of the Velox all the vessels are of the new heavy type. The *Erne*, for example, displaces 560 tons and the *Teviot* 580 tons. The Velox is something between the old and the new type, displacing 400 tons, and is thus at least 100 tons lighter than any of the others, the nearest to her being the other turbine boat, the Eden, which weighs 500 tons. A point of much interest is the steam consumption by the turbine vessels. Their engines cannot, of course, be indicated, and therefore the total coal consumption has to be taken; but assuming that they developed about 7000 horse-power at full speed, the consumption works out at between 2·35 lb. and 2·38 lb. per horse-power, or just comfortably within the basis consumption according to the Admiralty specification, viz., 2½ lb. This compares fairly with many of the results, but is well beaten by the four Yarrow boats, and, to make the comparison stronger, by the *Derwent* and *Waveney*, made by the builders of the turbine boats. All the trials are at full speed when the engines are working at their best.

TABLE CXXXVI.—COAL CONSUMPTION AND SPEED OF TORPEDO-BOAT DESTROYERS. RECIPROCATING *versus* TURBINE ENGINES.

Names of Destroyers.	By whom built.	Speed obtained on full-speed trials.	Consumption of Coal on the high-speed consumption trials. Per Hour. Total.	Per Horse-power Hour.	Average Air-pressure in the stokehold on the full-speed trial.
Velox (Turbine)	Hawthorn Leslie	27·1	7·85 tons	...	3·1
Erne	*Palmer's Co.*	*25·6*	...	*2·25* lbs.	*2·5*
Derwent	*Hawthorn Leslie*	*25·7*	...	*2·24* ,,	*2·8*
Foyle	*Laird Bros.*	*25·6*	...	*2·79* ,,	*4·4*
Ettrick	*Palmer's Co.*	*25·6*	...	*2·33* ,,	*2·6*
Eden (Turbine)	Hawthorn Leslie	26·2	7·45 tons	...	3·3
Waveney	*Hawthorn Leslie*	*25·6*	...	*2·19* ,,	*3·2*
Itchen	*Laird Bros.*	*25·6*	...	*2·46* ,,	*4·3*
Exe	*Palmer's Co.*	*25·6*	...	*2·11* ,,	*2·4*
Arun	*Laird Bros.*	*25·7*	...	*2·68* ,,	*4·4*
Cherwell	*Palmer's Co.*	*25·6*	...	*2·34* ,,	*2·7*
Usk	*Yarrow & Co.*	*26·1*	6·2 tons	*1·9* ,,	*1·6*
Blackwater	*Laird Bros.*	*25·7*	...	*2·62* ,,	*5·3*
Dee	*Palmer's Co.*	*25·5*	...	*2·28* ,,	*2·6*
Teviot	*Yarrow & Co.*	*25·9*	7·3 tons	*2·07* ,,	*2·0*
Kennet	*Thornycroft's*	...	...	...	...
Jed	*Thornycroft's*	...	...	...	...
Ribble	*Yarrow & Co.*	*25·8*	5·4 tons	*1·57* ,,	*1·6*
Welland	*Yarrow & Co.*	*26·2*	5·75 tons	*1·65* ,,	*1·8*

Service	Isle of Man Steam Packet Co.	G.W. Ry. Co., and G.S. Ry. (Ireland).
Name of Vessel	"Viking."	"St George." [1]
Date of launch	March 7, 1905	January 13, 1906
Name of builder	Armstrong, W. Co.	J. Brown & Co. Laird & Co.
Place	Walker	...
Vessel's length overall	361ft.	350ft.
Beam	42ft.	40ft.
Depth, upper deck to keel	17½ft.	...
Passenger accommodation	2000	...
Speed	24	23
Boilers	Wallsend Slipway	...
Pressure	150 lbs. per sq. in.	150 lbs.
Turbines	Parsons	Parsons' Turbines, 2300 tons, 430 R.p.m.
Displacement	1990 tons	
Passengers accommodated	1950 [2]	
Shafts	3	3
High-pressure Turbines: number	1 centre shaft	...
Low-pressure Turbines: number	2	...

[1] The "St George," "St Patrick," and "St David" will run between Fishguard, North Pembrokeshire, and Rosslare, Co. Wexford. The journey is 54 nautical miles (62 statute miles). Time, 2¾ hours.

[2] Season's work: 8880 nautical miles on 4210 tons of coal, 0·47 ton per N.M.; average speed, 22·4 knots. Economy over "Reciprocating" vessel on same route, 23 per cent., and one engineer, two greasers, and one fanman less staff.

Service	Turbine Steamers, Ltd., Captain John Williamson, Managing Director.				Larne and Stranraer Steamship Joint Committee.
Route	River Clyde Passenger Service, Greenock and Campbeltown.				
	Turbine Vessels.		*Reciprocating Engine Steamer for comparison.*		Turbine Vessel.
Name of Vessel	"King Edward."	"Queen Alexandra."	*Triple Expansion Estimate.*	*Duchess of Hamilton.*	"Princess Maud."
Built in year	1901	1902	...	...	...
Date of launch	May 16, 1901	April 8, 1902	...	...	Feb. 20, 1904
Date of trial	June 26, 1901	...	...	...	...
Name of builder	W. Denny & Bros.	W. Denny & Bros.	Messrs Denny	...	Denny
Place	Dumbarton	Dumbarton	...	...	Dumbarton
Vessel's length overall	250½ft.	270ft.	...	*250½ft.*	300 ft.
Vessel's length between perpendicular	250ft.	...	...	...	...
Beam	30ft.	32ft.	...	*30ft.*	40 ft.
Moulded depth to main deck	10½ft	...	*11½*	*10½ft.*	...
Depth to promenade deck	17¾ft.	18¾ft.	...	...	24ft. 6in.
Draught	6ft.	6½ft.	...	*6ft.*	10ft. 6in.
Rudders	...	...	...	...	Both forward and aft

	Turbine Vessels.		*Reciprocating Engine Steamer for comparison.*		
Name of Vessel	"King Edward."	"Queen Alexandra."	*Triple Expansion - Estimate.*	*Duchess of Hamilton.*	"Princess Maud."
Passenger accommodation for	1994	...	...	*1780*	...
Number of crew	50	...	...	*42*	...
1st class	...	...	...	...	...
2nd class	...	...	..	...	...
3rd class	...	...	...	...	...
Displacement	700 ...	...	...	...	1900
Registered tonnage	562	...	...	...	...
Speed forward	20·48 knots	21·63 knots	*19·7 knots*	*18 knots*	20·66 knots
Speed astern	...	...	...	...	...
Length of journey	...	..	...	...	...
Average running speed	...	...	...	...	...
Horse-power, from Messrs Denny's tank experiments	3500	4400	*2800*	...	6000
Boilers:—					
Maker	Denny & Co. 8 furnaces	Denny & Co.	...	...	...
Type	Return tube double-ended.	Large double-ended	...	...	...
Number installed	1	1 slightly larger than "King Edward."	...	...	...
Rated capacity (lbs. per hour)	...	...	...	...	...
Heating surface, total	...	...	...	...	...
Grate area	...	...	...	...	..
Draught pressure (water)	...	1·1 ins.	...	...	...
Steam pressure	150 lbs. per sq. in.	150 lbs per sq. in.	...	...	150 lbs.
Feed-heater receives steam exhaust from	Auxiliaries.	...	...	...	...
Funnels:—					
Number	2	2	...	...	...
Diameter	...	...	...	...	...
Superheaters	None.	None.	...	...	...
Shafts:—					
Number	3	3	...	...	3
Diameter	...	...	...	...	...
Weight	...	...	...	...	...
Propellers:—					
Total number	5	5	...	...	3
Per shaft	Centre shaft. 1 / Each side. 2	Tandem side[1] propellers,	...	...	...
Number of blades each	... ...	...	...	...	...
Diameter	57ins. 40ins.	One. 48ins. / Four. 36ins.	...	...	60 ins.
Distance apart	... 9ft.	...	...	...	...
Rudders	...	...	...	...	at both ends

[1] "Queen Alexandra's" propellers changed 1908 to one each shaft.

	Turbine Vessels.		*Reciprocating Engine Steamer for comparison.*		
Name of Vessel . .	"King Edward."	"Queen Alexandra."	*Triple Expansion Estimate.*	*Duchess of Hamilton.*	"Princess Maud."
Steam Turbine:—					
Made by . . .	Parsons	Parsons	...	...	...
Number . . .	3	3	...	...	...
Steam steering gear by .	...	Bow, M'Lachlan & Co., Paisley	...	...	...
High-pressure Turbines:—					
Number . . .	1	1	...	..	...
Position . . .	Centre shaft	Centre shaft	...	...	...
Revolutions per minute	500	750	...	...	600
Expansion . . .	Five-fold	...	...	...	...
Low pressure Turbines:—	...	...	..	...	...
Number . . .	2	2	...	...	...
Position . . .	Each side shaft	Each side shaft	...	...	...
Revolutions per minute	750	1100	...	...	...
Expansion . . .	25-fold	...	...	...	...
Total expansion . .	125-fold	...	...	...	...
Go-astern Turbines:—					
Number . . .	2	2	...	...	...
Position . . .	Inside exhaust end of l. p. turbines	Inside exhaust end of l.p. turbines	...	...	...
Revolutions per minute	...	...	...	...	...
Rated H.-p. condensing .	...	...	...	...	...
Rated horse-power non-condensing	...	...	...	...	...
For comparison: Reciprocating Engines in other vessels	...	...	...	...	...
Piston Engines:—					
Maker	...	...	...	...	...
Type	...	...	*Triple*	*Compound*	...
Number . . .	...	...	...	...	...
Cylinders diameters .	...	...	...	...	...
Revolutions per minute full speed	...	...	...	...	...
Stroke	...	...	...	...	...
Rated power condensing	...	...	...	..	...
Rated power non-condensing	...	...	...	...	...
Steam consumed . .	...	...	...	...	...
Weight of steam per I.H.P. hour full speed	...	under 15 lbs.	...	...	...
Coal burned per hour full speed	See table below	...	...	...	..
Main Condensers:—					
Made by . . .	...	...	...	...	...
Type	...	...		...	...
Number . . .	...	...	...	...	...
Surface . . .	...	...	...	...	...
Surface of augmenter (if any)	...	...		...	...
Power used by augmenter	...	...	...	...	...

	Turbine Vessels.		*Reciprocating Engine Steamer for Comparison.*		
Name of Vessel . .	"King Edward."	"Queen Alexandra."	*Triple Expansion Estimate.*	*Duchess of Hamilton.*	"Princess Maud."
Air Pump :—					
Driven	by worm on l.p. turbine shaft	from circulating engines	...	...	...
Maker	...	...	...	...	...
Type	...	...	...	...	...
Vacuum maintained at full speed	26·5 inches	26·5 inches	...	..	...
Temperature of discharge at full speed	...	...	...	...	...
Steam per hour used at full speed	...	...	...	...	... ...
Air pump barrel diameter and stroke	...	...	...	. .	...
Steam cylinder—diam.	...	...	...	...	...
Strokes per minute .	...	...	...	...	...
Circulating Pump :—	...	...	...	...	...
Made by	...	...	...	...	...
Type	...	...	...	...	...
Steam per hour at full speed	...	...	...	...	...
Weight of circulating water per unit weight of steam	...	...	...	...	...
Temperature suction .	...	...	...	...	...
,, discharge .	...	...	...	...	..
Electric-lighting Engine:—				*Steam Turbine*	... ...
Maker	...	...	...	*Parsons*	...
Type	...	...	...	...	...
K.W. capacity each .	...	...	...	...	...
Position . . .	...	...	...	...	...
Photo of vessel . .	See fig. 458[1]	Fig. 459	...	...	...
Feed Pumps :—					
Made by	...	...	...	...	...
Type	...	...	...	...	...
Number	...	...	...	...	...
Water cylinder diameter stroke	...	...	...	...	...
Steam cylinder diameter	...	...	...	...	...
Capacity per hour	...	...	...	...	
Steam consumed per hour	...	...	...	...	...
Oil circulation	...	...	...	...	...
Steam consumed per hour	...	...	...	...	...
Weights of machinery :—					
Boilers, including water	...	...	...	...	...
Turbine machinery .	...	...	...	...	...
Shafting	...	...	...	...	...
Total	66 tons	...	...	...	...
When firing all Boilers :—					
Mean speed on measured mile	20·48	21·63	19·7	18·1	..
Steam Pressure at boilers per sq. in.	...	...	...	...	...

[1] From *Clyde Passenger Steamers* 1812 *to* 1901, by Captain James Williamson. MacLehose & Sons (1904), Glasgow.

	Turbine Vessels.		*Reciprocating Engine Steamer for Comparison.*		
Name of Vessel . .	"King Edward."	"Queen Alexandra."	*Triple Expansion Estimate.*	*Duchess of Hamilton.*	"Princess Maud."
Vacuum inches mercury	...	...	...	...	...
Revolutions per minute h.p. turbine	505	750	...	...	...
Revolutions per minute l.p. turbine	755	1090	...	...	...
Revolutions per minute reciprocating engines	...	...	...	...	...
Average sea speed on 160 miles run to Campbeltown and back	1901 season 19 knots	...	$18\frac{1}{2}$	$16\frac{1}{2}$	...
Average coal consumed, including lighting, per day	18 tons	...	22 estimate	16	...
Average coal consumed per equivalent I.H.P. hour	1·8 lbs.	...	...	...	...

Fig. 458.—"King Edward."

Fig. 459.—"Queen Alexandra."

TABLE CXXXVII.—COMPARISON OF COAL CONSUMPTION.

Vessel	"King Edward."	*Similar type Reciprocating.*	*Duchess of Hamilton.*
Days running	79	*80*	...
Total knots	12,116	*12,106*	*15,604*
Total of coal burnt	1430 tons	*1909 tons*	*1759 tons*
Average speed	18½ knots	18½ knots	*16½ knots*
Coal per mile at same speed	264 lbs.	353 lbs.	253 lbs.
Miles per ton of coal	8½	6⅜	9
Authority	Capt. Williamson	*Capt. Williamson*	*The Mechanical Engineer*, Feb. 1, 1902

STEAM TURBINE YACHTS.

Name of Vessel	"Narcissus"	"Emerald"	"Lorena"	"Libellule"	"Albion"
Built for	A. E. Miller Mondy, Derby	Sir Christopher Furness	Mr A. L. Barber, New York	...	Sir George Newnes
Now owned by	...	Mr Gould	...	...	...
Type	Turbine yacht	...	...	...	...
Built in year	...	1903	1903	...	...
Date of launch	Dec. 20, 1904	Oct. 21, 1902	...	...	Nov. or Dec. 1904
Name of designer	...	F. J. Stephen	Cox & King, London	...	...
Name of builder	Fairfield	A. Stephen & Son Ltd.	Ramage & Ferguson,	...	...
Place	...	Glasgow	Leith	...	...
Vessel's length	245ft.	236ft.	253ft.	...	270ft.
Length between perpendicular	...	198ft.	...	...	...
Beam	27½ft.	28ft. 8in.	33ft. 3in.	...	34ft.
Beam, including rolling chocks	...	...	...	...	...
Depth, moulded	16¼ft.	18ft. 6in.	20ft. 3in.	...	20ft.
Depth, upper deck to keel	...	...	...	...	...
Depth, promenade deck to keel	...	...	...	...	...
Draught	...	...	13ft.	...	...
Passenger accommodation—					
Tonnage, by yacht measurement	782	756	1400	...	...
Displacement	...	900 tons	1303 tons	...	1300
Speed forward	...	15 knots	18·02 knots[1]	...	15 knots
,, astern	...	...	...	...	...
Length of journey	...	...	...	...	...

[1] With 240 tons of coal on board.

His Majesty the King of England's yacht is equipped with turbines. The "Mahroussa," the Khedive's yacht, is also equipped with turbines. See p. 631, items 60 and 61.

STEAM TURBINE YACHTS—*continued.*

Name of Vessel	"Narcissus"	"Emerald"	"Lorena"	"Libellule"	"Albion"
Average running speed	14½	...	...	...	...
Horse-power I.H.P.	1250	1500	3500	...	1800
Boilers	2	...	...	...	...
Maker	...	...	...	...	...
Type	Multitubular	...	Single-ended Scotch	...	...
Number installed	...	...	4	...	...
Rated capacity (lbs. per hour)	...	...	...	...	...
Heating surface, total	...	...	8560	...	...
Grate area	...	...	217	...	...
Draught (water) pressure	...	...	Howden's	...	...
Forced draught—type	...	...	...	...	...
Steam pressure—lbs. per sq. inch.	180 lbs.	150 lbs.	180	...	150
Funnels:—					
Number	...	...	...	...	...
Diameter	...	...	...	...	...
Superheaters:—	...	...	none	...	..
Shafts	...	...	...	...	...
Number	...	3	3	...	...
Diameter	...	...	...	...	..
Weight	...	...	...	...	..
Propellers, per shaft	...	1	1	...	...
Total	...	3	3	...	3
Number of blades each	...	...	56in.	...	...
Diameter	...	...	48in.	...	...
Steam turbine	...	...	...	Rateau	...
Made by	...	Parsons	Parsons, weight [1]	...	...
Type	...	...	...	...	..
Cruising Turbine:—					
Number	...	...	...	...	...
Position	...	...	...	...	...
High-pressure Turbines:—					
Number	1	1	1	...	1
Position	...	Centre shaft	Centre shaft	...	...
Revolutions per minute	...	500	550	...	...
Low-pressure Turbines:—					
Number	1	2	2	...	2
Position	...	Each side shaft	Each side shaft	...	..
Revolutions per minute	...	700	700	...	...
Go-astern Turbines:—					
Number	...	...	...	...	...
Position	...	...	...	Inside l.p. end of main turbine	...
Revolutions per minute	...	...	...	...	...
Rated horse-power condensing	...	...	...	...	...
Rated horse-power non-condensing	...	...	...	...	...
Steam consumed	...	...	...	...	...
Weight of steam per hour full speed	...	...	...	...	...

[1] 70 tons less weight than the reciprocating machinery originally designed for the "Lorena."

Steam Turbine Yachts—*continued.*

Name of Vessel.	"Narcissus."	"Emerald."	"Lorena."	"Libellule."	"Albion."
Weight of steam per hour half speed	...	...	...	...	...
Coal burned per hour full speed	...	...	...	...	...
Coal storage	...	...	500 tons	...	...
Condenser—					
Made by	...	...	...	...	...
Type	...	...	Surface	...	...
Number	...	...	2	..	...
Air Pump	...	...	2	...	...
Maker	...	...	...	...	...
Type	...	...	...	...	...
Vacuum maintained at full speed	...	...	...	...	...
Temperature of discharge at full speed	...	...	...	...	...
Steam per hour used at full speed	...	...	...	...	...
Air pump barrel, diameter and stroke	...	...	...	...	...
Steam cylinder — diameter	...	...	...	...	...
Strokes per minute	...	...	...	...	...
Circulating pump	...	...	2	...	...
Made by	...	...	...	...	...
Type	...	...	...	...	...
Steam per hour at full speed	...	...	...	...	...
Weight of circulating water per unit weight of steam	...	...	...	...	...
Temperature suction	...	...	...	...	...
Temperature discharge	...	...	...	...	...
Electric-lighting engine:—					
Maker	...	...	...	...	...
Type	...	...	...	...	...
K.W. capacity each	...	...	...	...	...
Position	...	...	...	...	...
Photograph of vessel	...	...	Fig. 460	...	...
Feed Pumps:—					
Made by	...	...	Weir	...	...
Type	...	...	...	...	...
Number	...	...	2	...	...
Water cylinder diameter	...	...	...	...	...
Stroke	...	...	...	...	...
Steam cylinder diameter	...	...	...	...	...
Capacity per hour	...	...	...	...	...
Steam consumed per hour	...	...	...	...	...
Oil circulation Pumps:—					
Number	...	...	2	...	...
Type	...	...	Weir	...	...
Steam consumed per hour	...	...	...	...	...
Weights:—					
Boilers, including water	...	...	...	...	...
Turbine machinery	...	...	...	...	...

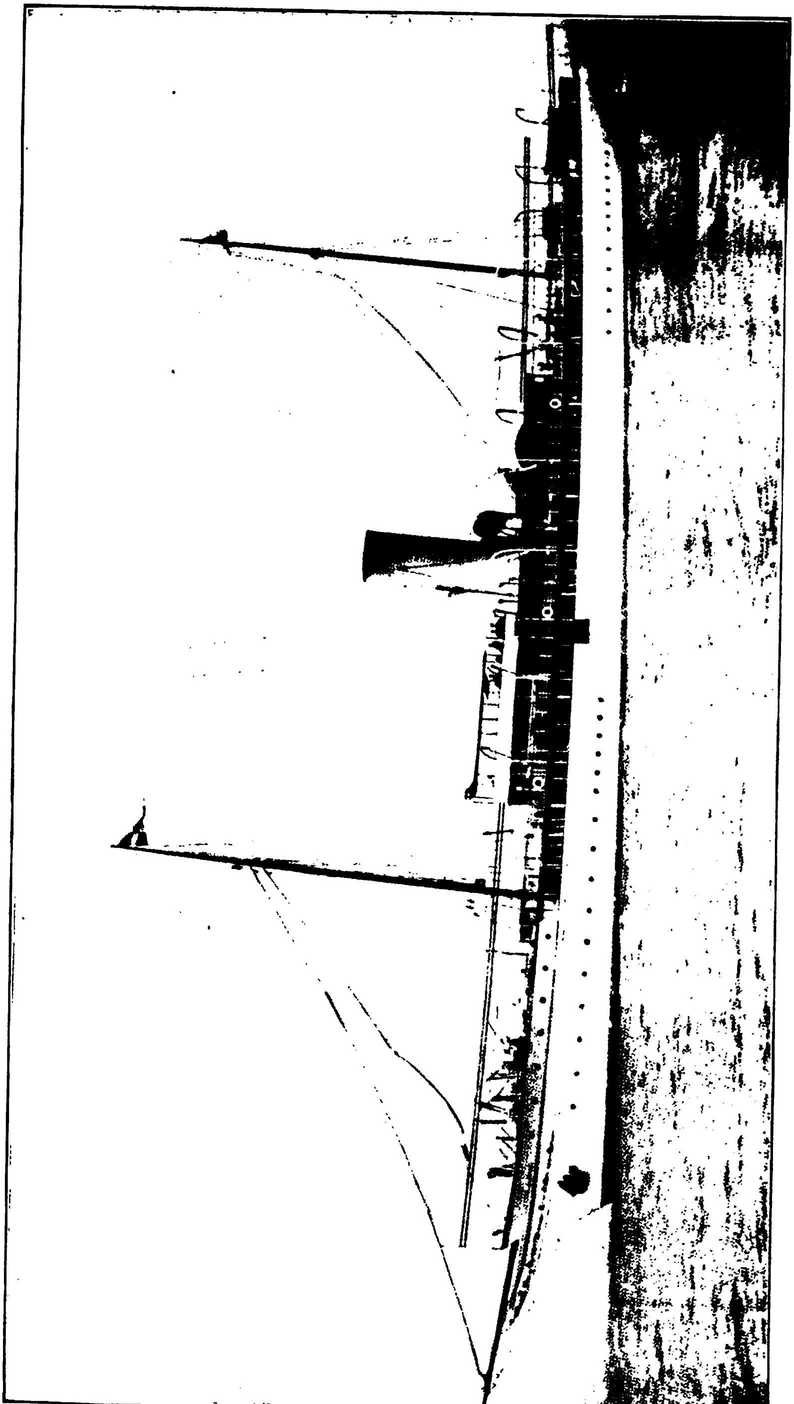


FIG. 460.—S.T.Y. "Lorena." Built 1903.
Length 253 Ft., Beam 33 Ft. 3 In., 18 Knots, 1400 Tons Yacht Measurement.

STEAM TURBINE YACHTS—*continued.*

Name of Vessel	"Narcissus."	"Emerald."	"Lorena."	"Libellule."	"Albion."
Main reciprocating engines	...	...	...	...	...
Shafting	...	...	...	...	...
Total	...	...	...	...	...
Costs	...	...	...	...	...
Test Results:—					
When firing	...	...	2 boilers	...	...
Run from	..	...	New York	...	...
Run to	...	...	Tompkinsville, S.I.	...	...
Steam pressure at boilers	...	...	180lbs.	...	...
At stop valve	...	...	160lbs.	...	...
In h.p. Turbine	...	...	100lbs.	...	...
In l.p. Turbine	...	...	20lbs.	...	...
Vacuum (mercury)	...	...	27ins.	...	...
Revolutions per minute:—					
Centre Turbine	...	...	300	...	...
Wing Turbines	...	...	350	...	...
Air and circulating pumps	...	...	100	...	...
Mean speed on measured mile	...	15	18·02	...	15
			Full speed / Half speed		
Steam pressure at boilers per sq. in.	...	...	180 / 180	...	...
Steam pressure in h.p. Turbine	...	...	150 / 50	...	...
Steam pressure in l.p. Turbine	...	...	25 / 5	...	...
Vacuum inches mercury	...	...	27 / ...	...	...
Revolutions per minute h.p. Turbine	...	..	500	...	...
Revolutions per minute l.p. Turbines	...	...	600	...	...

STEAM TURBINE VESSELS BUILT BY MESSRS YARROW & CO., LTD.

	Turbine Steam Yacht.	Reciprocating and Turbine Steam Yachts.	
Name of Vessel	"Tarantula."	"Caroline."	"No. 1125."
Built for	Col. M'Calmont	...	...
Owned by	Mr W. K. Vanderbilt,	Russia	...
Date of launch	1902	1904	...
,, test	...	...	Jan. 19, 1904
Name of designers	Cox & King	Yarrow	Yarrow
Name of builder	Yarrow & Co., Ltd.,	Yarrow	Yarrow

Data kindly supplied by Messrs Yarrow & Co.

STEAM TURBINE VESSELS—*continued.*

	Turbine Steam Yacht.	Reciprocating and Turbine Steam Yachts.			
Name of Vessel	"Tarantula."	"Caroline."		"No. 1125."	
Place	Poplar, London	Poplar		Poplar	
Vessel's length overall	152ft. 6in.	152ft. 6in.		152ft. 6in.	
Length between perpendicular	...	...		...	
Beam	15ft. 3in.	15ft. 3in.		15ft. 3in.	
Depth	8ft. 5in.	8ft. 5in.		8ft. 5in.	
Tonnage by yacht measurement	170	...		...	
Displacement	150 tons	140 tons		140 tons	
Draught	5 ft.	5ft.		...	
Speed, knots forward	26·75	26·4		26·4	
" astern	...	Reciprocating 10/14 knots		Reciprocating 10/14 knots	
Length of journey	...	...		...	
Average running speed	22	...		...	
Horse-power	2000	2000		2000	
Boilers:—					
Maker	Yarrow & Co.	Yarrow		Yarrow	
Type	*Yarrow*	Yarrow		Yarrow	
Number installed	2	2		2	
Rated capacity (lbs. per hour)	...	...		...	
Heating surface, total	3600 sq. ft.	3600 sq. ft.		3600 sq. ft.	
Grate area, total	70 sq. ft.	70 sq. ft.		70 sq. ft.	
Draught pressure (water)	...	...		...	
Steam pressure—lbs. per sq. in.	225	235		235	
Funnels:—					
Number	2	2		2	
Diameter	...	...		...	
Superheaters:—	none	none		none	
Shafts:—					
Number	3	3		3	
Diameter	...	...		...	
Weight	...	...		...	
Propellers:—					
Total	6[1]	3, later 5		3	
per shaft	...	centre	sides[2]	centre	sides
Number of blades each	...	...	...	3	3
Diameter	37in.	48in.	32in.	45in.	32in.
Pitch	...	66in.	30in.	66in.	34in.
Steam Turbine:—					
Made by	Parsons	Oerlikon Works		Yarrow	
Type	...	Rateau Turbines		Parsons	
Number	3	2		2	
Recip. Engine	none	250 B.H.P.		250 B.H.P.	
Course of steam	...	.. [3]		...	
Reciprocating Engine:—					
Number	none	1		1	
Horse-power	...	250		250	
Position	...	centre shaft		centre shaft	
Revolutions per minute	...	...		575	

[1] Later 36in. propeller on each shaft.

[2] See p. 682 for the five propellers; only the original 3 are referred to here.

[3] Reciprocating engine takes steam from boiler and delivers exhaust to condenser. Turbines do likewise.

STEAM TURBINE VESSELS—*continued.*

	Turbine Steam Yacht.	Reciprocating and Turbine Steam Yachts.	
Name of Vessel	"Tarantula."	"Caroline."	"No. 1125."
Cruising Turbine :—			
Number	1	none	none
Position	..	...	...
High-pressure Turbines :—			
Number	...	1	1
Position	...	side shaft	side shaft
Revolutions per minute . .	1000	1500	1350
Direction rotation . . .	...	right-handed	left-handed
Low-pressure Turbines :—			
Number	...	1	1
Position	...	side shaft	side shaft
Revolutions per minute . .	930	1500	1350
Direction rotation . . .	...	left-handed	right-handed
Go-astern Turbines :—			
Number	...	...	...
Position	...	...	...
Revolutions per minute . .	...	...	...
Rated horse-power condensing .	...	...	...
Rated horse-power non-condensing	...	...	...
Steam consumed	...	...	...
Weight of steam p. hour full speed	...	...	...
Weight of steam per hour half speed	...	...	...
Fuel burned per hour at full speed	...	...	...
Condenser :—			
Made by	...	...	...
Type	surface	surface	surface
Number	2	...	...
Surface	...	...	...
Surface of augmenter (if any) .	...	...	...
Power used by augmenter (if any)	...	...	...
Air Pump	1	...	...
Maker	...	...	...
Type	...	Two installed, only one used	...
Vacuum maintained at full speed [1]	21in.	27in.	27½ins.
Temperature of discharge at full speed	...	...	...
Steam per hour used at full speed	...	...	...
Air pump barrel dia. and stroke	...	...	...
Steam cylinder—diameter .	...	...	..
Strokes per minute . .	...	...	..
Circulating Pump . . .	1	1	1
Type	...	...	..
Steam per hour at full speed .	..	...	..
Weight of circulating water per unit weight of steam	...	...	..
Temperature suction . .	...	...	...
Temperature discharge, . .	...	...	...

[1] "Tarantula": On run from New York to Great Neck, vacuum 21in.

STEAM TURBINE VESSELS—*continued.*

	Turbine Steam Yacht.	Reciprocating and Turbine Steam Yachts.	
Name of Vessel	"Tarantula."	"Caroline."	"No. 1125."
Electric-lighting Engine:—			
Maker	..	...	.
Type	...	...	...
K.W. capacity each	3½	...	...
Position	...	...	...
Drawings of vessel	...	Fig. 462/8	...
of turbine	...	Figs. 469/70	...
of condensing plant	...	...	...
of reciprocating engines	...	...	...
Illustration of vessel	Fig. 461	...	...
of Turbines	...	...	...
Feed Pumps:—			
Made by	...	Weir	Weir
Type	...	vertical	vertical
Number	...	1	1
Water cylinder diameter stroke	...	...	...
Steam cylinder diameter	...	...	...
Capacity per hour	...	...	..
Steam consumed per hour	...	...	...
Oil circulation pumps	2	2	2
Oil pressure, lbs. per sq. in.	5·75	...	...
Steam consumed per hour	...	...	...
Weights:—			
Boilers, including water	...	...	...
Turbine machinery—lbs.	...	17,200[1]	...
Main reciprocating engines	...	...	...
Shafting	...	...	...
Total	...	...	...
Costs	...	...	...
Test Results	..	Tables below	...
When firing how many boilers?—			2
Guaranteed speed	...	...	
Six hours' trial speed	...	...	...
Mean speed on measured mile	...	...	26·4
When firing all boilers:—			
Guaranteed speed	...	...	...
Mean speed on measured mile	25·36	...	...
With displacement	150 tons	...	...
Steam pressure at boilers, lbs. per sq. in.	225	235	235
in H.P. turbine	200	170	230
in L.P. turbine	...	10½	30
Vacuum, inches mercury	21	27	27½
Revolutions per minute H.P. Turbine	..	...	...
		..	...
L.P. Turbine	...	...	...
reciprocating engines	...	...	...
Fuel	liquid[2]	Welsh coal	Welsh coal

[1] Capable of over 2000 horse-power; *i.e.*, 8·6 lbs. weight per horse-power output.

[2] *Die Turbine*, p. 23, Oct. 1904.

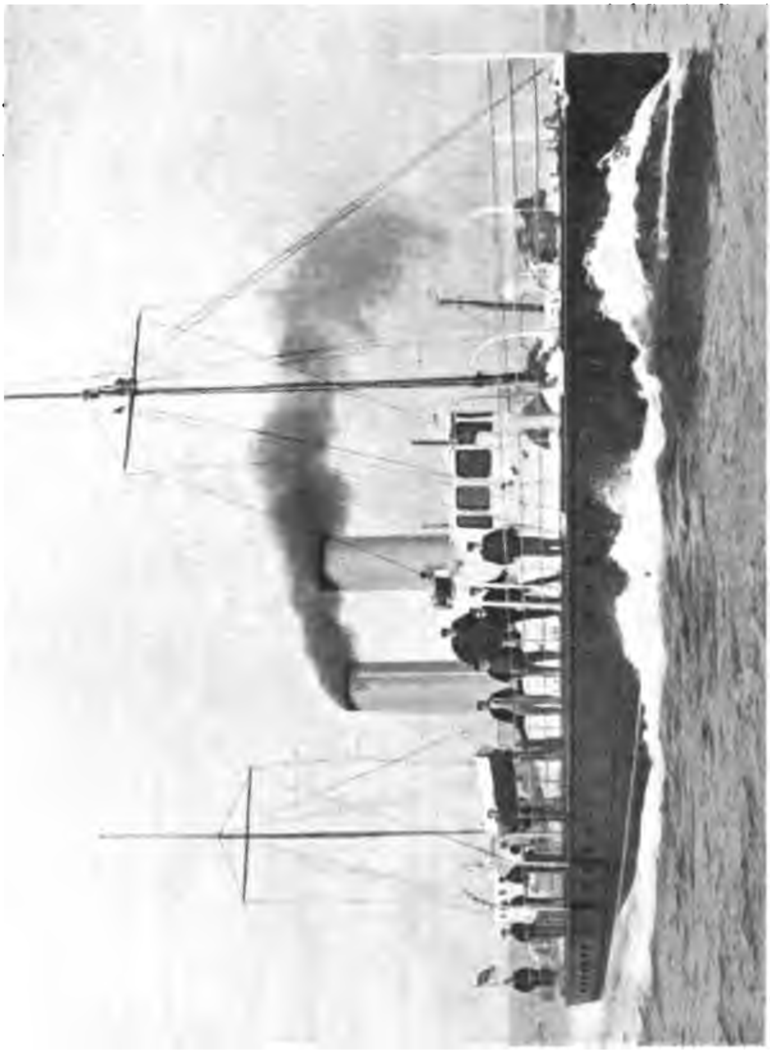
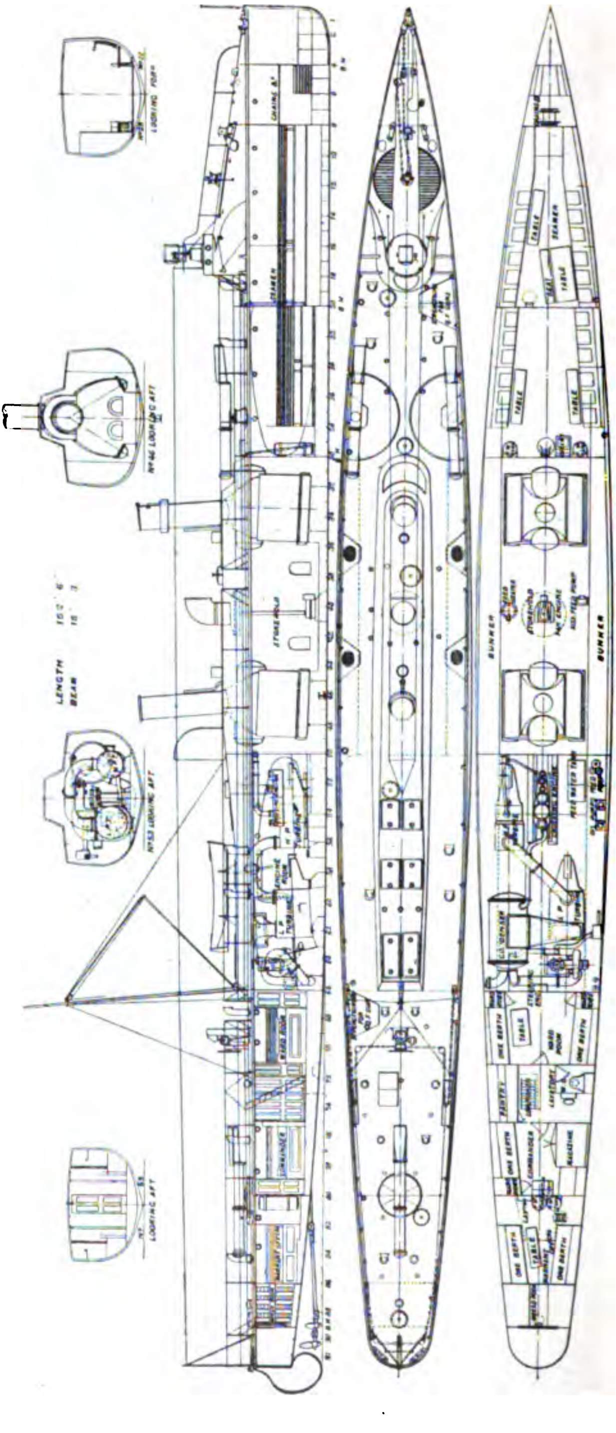


FIG. 461.—S.Y. "Tarantula." *Equipped with Parsons Turbines* 1902. *Built by Messrs Yarrow & Co. Designed by Messrs Cox & King.*

Length $152\frac{1}{2}$ *Ft., Breadth* $15\frac{1}{4}$ *Ft., Depth* $8\frac{1}{8}$ *Ft.* 171 *Tons Thames Measurement.* $26\frac{3}{4}$ *Knots.*



FIGS. 462 to 468.—S.T. Yacht "Caroline." Built by Messrs Yarrow & Co. Equipped with Rateau Steam Turbines and Reciprocating Engine.
(*Proc. Inst. Naval Architects*, 1904.)

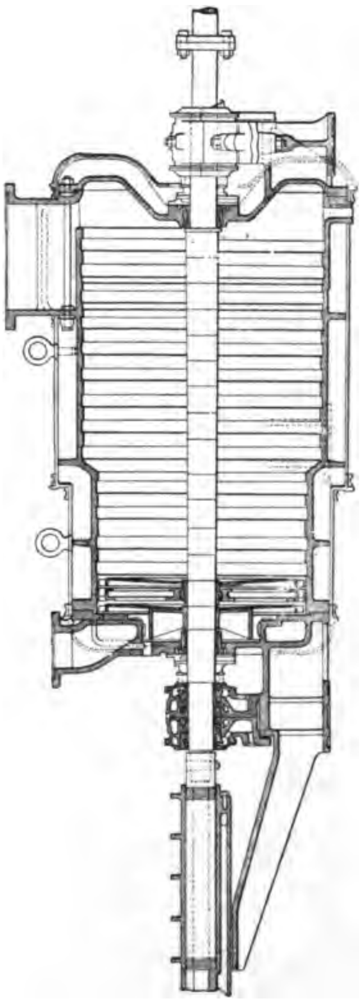


Fig. 469.

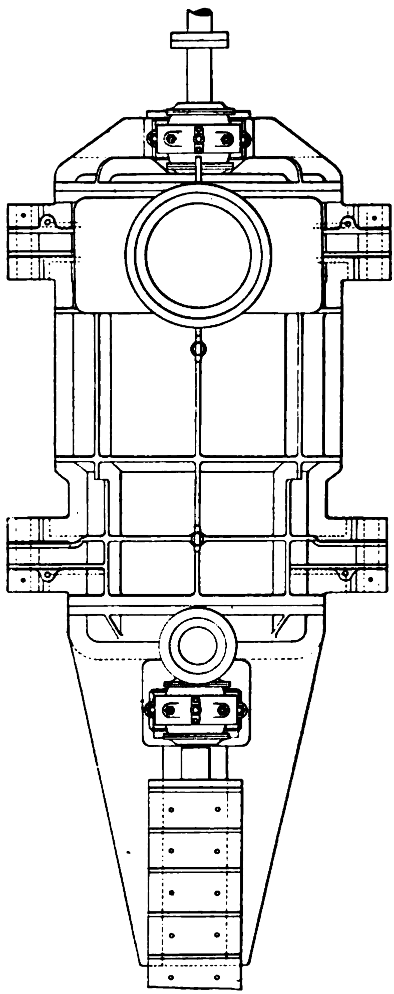


Fig. 470.

Figs. 469 and 470.—Plan and Elevation of Rateau Steam Turbine in the "Caroline." Scale: 1/26 full size.

STEAM TURBINE VESSELS—*continued.*

	Steam Turbine Yacht.	Reciprocating and Turbine Steam Yachts.	
Name of Vessel	"**Tarantula.**"	"**Caroline.**"	"**No 1125.**"
Estimated from calculations for design :—			
Efficiency	..	61 per cent.	...
Maximum	...	2000 H.P.	2000 H.P.
Normal speed, revolutions per minute	...	1500/1600	1350
Loss due to friction between rings and steam	...	...	...
in H.P. .	..	41 H.P.	...
in per cent.	...	2 per cent.	...
With steam pressure per sq. in.	..	170 lbs.	...
and vacuum	.	27in.	...
The steam consumption was calculated to be in lbs. per effective H.P. hour	8·2 / ·61	13·4 lbs.[1]	...

[1] This corresponds to 11·7 lbs. per I.H.P. hour for a reciprocating engine having 12 per cent. loss due to internal friction.

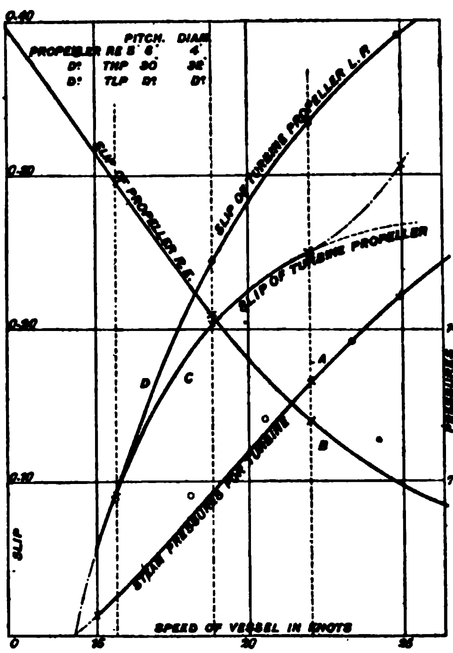


FIG. 471.—Tests by Messrs Yarrow & Co., Ltd., of "Caroline," Oct. 1903.
Rateau Turbines and Reciprocating Engine.

TABLE CXXXVIII.—"Caroline": RESULTS OF FIRST TESTS OF MESSRS YARROW & CO.'S TORPEDO BOAT FITTED WITH ONE RECIPROCATING ENGINE AND TWO RATEAU TURBINES. (Fig. 471.)

Trials run October 13*th*, 1903 (*wind rather strong*).

Each of two turbine shafts had a three-bladed propeller, 32 in. diam. 30 in. pitch.
The centre (reciprocating engine) shaft had a propeller 48 ,, 66 ,,

Number of Trial.	I.	II.	III.	IV.	V.
Number of runs on measured mile	3	2	2	2	3
Number of propellers . . .	3	3	3	3	3
Effective pressure of steam on admission to high-pressure turbine, lbs. per sq. in. . . .	zero	5·0	50	100	145
Condenser vaccuum—inches .	26·8	28	28	27·2	26·9
Speeds attained in various runs —in knots	10·68 13·50 10·30	17·39 13·70 ...	20·66 16·76 ...	23·84 20·00 ...	27·69 22·36 27·48
Mean speed of vessel—in knots	11·98	15·54	18·71	21·92	24·97
Revolutions per minute of reciprocating engine	369	411	441	475	516
Revolutions per minute of high-pressure turbine	393 [1]	688	955	1172	1455
Revolutions per minute of low-pressure turbine	395 [1]	687	994	1357	1657
E.H.P. developed on shaft of reciprocating engine . .	239	260	251	235	232
Slip of propellers driven by reciprocating engine . . .	39·5%	29·7%	21·0%	14·0%	9·7%
Slip of propellers driven by high-pressure turbine . . .	...	8·9%	20·6%	24·5%	30·5%
Slip of propellers driven by low-pressure turbine . . .	...	8·9%	24·0%	35·0%	39% [2]

The E.H.P. developed on shaft was arrived at by deducting 10 per cent. recorded by the Watt indicator.

[1] In the first trial the reciprocating engine alone received steam, while the turbines revolved idly, due to the action of the water on their propellers. The other trials were made with progressively increased steam pressure, supplied to the high-pressure turbine.

[2] The low-pressure turbine gave more power than the high-pressure turbine, due, Professor Rateau stated, to the condenser giving better results than were anticipated.

The complete absence of vibration was especially noteworthy.

Additional Propellers on "Caroline's" Turbine Shafts.—Curves B, C, and D, Fig. 471 (opposite), showed that the propeller surface was rather too small for speeds above 21 knots A second propeller was consequently added to each of the turbine shafts.

Table CXXXIX.—Results of Second Tests of Messrs Yarrow & Co.'s Torpedo-Boat.

Trials run January 19th, 1904, with 5 propellers.

On the middle shaft (reciprocating engine) one propeller		42 in. diam.	66 in. pitch.
,, one side shaft (high-press. turbine) two ,,		28 ,, 32 ,,	30 ,, 30 ,,
,, other side shaft (low ,, ,,) ,, ,,		28 ,, 34 ,,	30 ,, 34 ,,

Number of Trial	I.	II.	III.	IV.
Effective pressure of steam on admission to high-pressure turbine—lbs. per sq. in.	50	100	150	170[1]
Condenser vacuum — inches of mercury	28	27·5	27	27
Speed of vessel (two runs) — knots	15·58 20·00	19·25 23·53	23·22 26·67	25·71 27·07
Mean speed of vessel—knots	17·79	21·39	24·94	26·39
Revolutions per minute of reciprocating engine	458	508	555	576
Revolutions per minute of high-pressure turbine	836	1052	1207	1258
Revolutions per minute of low-pressure turbine	836	1065	1232	1307
Slip of propellers driven by reciprocating engine	28·7%	22·4%	17%	15·3%
Slip of propeller driven by high-pressure turbine	13·6%	17·4%	16·4%	14·8%
Slip of propeller driven by low-pressure turbine	24·0%	28·2%	27·8%	27·8%

[1] The turbines were designed for 156 lbs. per sq. in. For the same steam consumption the speed is less than on October 13th, 1903 (see previous records, p. 681), except at maximum speed.

The two screws on each turbine shaft give better results than the single screws in the previous trials, but the efficiency of the turbines is much less, their speed having been greatly reduced.

The added screws, located near the hull, gave rise to considerable vibration.

To obtain the estimated efficiency of the turbines it was necessary to reduce the propeller surface and allow the turbines to revolve faster; this was done for the third set of trials.

TABLE CXL.—RESULTS OF THIRD TESTS OF MESSRS YARROW & Co.'S TORPEDO-BOAT.

Trials run March 4th, 1904

On the middle shaft (reciprocating engine)	1 propeller	42 in. diam.	66 in. pitch.
,, one side shaft (high-pressure turbine)	2 ,,	25 ,, 28 ,,	30 ,, 30 ,,
,, other side shaft (low ,, ,,)	2 ,,	25 ,, 30 ,,	30 ,, 30 ,,

Effective pressure of steam on admission to h.p. turbine	same as in Table CXXXIX.
Condenser vacuum	,, ,,
Mean speed of vessel	approximately as in Table CXXXIX.
Revolutions per minute of reciprocating engine	,, ,, ,,
,, ,, turbines	16% higher than ,,
Slip of propeller driven by reciprocating engine	same as in Table CXXXIX.
,, ,, high-pressure turbine	24·6%.
,, ,, low ,, ,,	33·1%.

The following is a summary of Professor Rateau's conclusions from these tests:—

1. The highest efficiency is obtained with a single propeller on each shaft.

2. It seems difficult to get satisfactory slip with propellers grouped on each shaft.

3. A slip of 25 per cent. seems to be the maximum for good duty; and in order that this shall not be exceeded, the propelling surface (and diameter) must be increased.

4. The inclination of the shafts in the boat under test is greater than it should be with propellers having a diameter greater than the pitch.

5. The speed of 26·4 knots has been attained; and the maximum obtained with reciprocating engines can, no doubt, easily be reached.

6. The necessity for nearly horizontal shafts calls for new lines of hull.

7. At reduced speeds the turbines are not economical.

8. Turbines alone are inconvenient for going astern and for manœuvring.

9. The reciprocating engine should exhaust into the low-pressure turbine.

10. Such a reciprocating engine supplying 40 per cent. of the power, and turbines the remaining 60 per cent., would give a vessel 15 per cent. to 20 per cent. more power than could be obtained with reciprocating engines only, and would add the general advantages characteristic of turbines.

Service . . . . South-Eastern and Chatham Railway Co.

Route . . . Dover—Calais.

	Turbine Steamers.			*Reciprocating Engine Steamer.*
Name of Vessel . . .	"Queen."	"Onward."	"Invicta."	*Victoria.*
Date of launch . . .	April 4, 1903	March 11, 1905	April 19, 1905	...
In regular passenger service .	June 28, 1903	Spring 1905	July 1905	
Name of builder . . .	Denny	Denny	Denny	..
Place	Dumbarton	Dumbarton	Dumbarton	...
Vessel's length overall . .	310ft.	310ft.	310ft.	...
Beam	40ft.	40ft.	40ft.	...
Moulded depth . . .	...	26ft. 6in.	24ft. 6in.	. .
Depth	...	...	...	
,, Promenade deck to keel	25ft.	...	...	...
Draught	10½ft.	10½ft.	.	.
Watertight bulkheads, number	...	...	...	...
Passenger accommodation, registered	1250	...	...	770
1st class	...	...	...	...
2nd class	...	...	..	...
3rd class	...	...	..	...
Displacement	1676 tons	1700 tons	...	. .
Net register	1129	...	..	...
Speed forward—knots .	22	23	23	18
Speed astern—knots . .	13	...	...	...
Length of journey . . .	25 N.M.	...	...	...
Time on journey . . .	59 minutes Aug. 15, 1903	...	52 minutes Aug. 1905	...
Running speed—knots . .	...	...	...	...
Horse-power I.H.P. .	8000/9700	8000	8000	...
Boilers :—				
Maker	...	...	...	..
Type	...	...	.	...
Number single-ended . .	2	...	.	...
Number double-ended . .	2	...	...	..
Rated capacity, lbs. per hour	...	..	...	...
Heating surface, total . .	...	...	...	...
Grate area	...	...	.	...
Draught pressure (inches water)	¾ to 1¼	...	...	...
Steam pressure (lbs. per sq. in.)	150	150	150	...
Funnels :—				
Number	2	...	...	...
Diameter	...	...	...	...

London, Brighton, and South Coast Railway Co. and Chemin de Fer de l'Ouest.

Newhaven and Dieppe.

Union S.S.[1] Co. of New Zealand.

British India Steam Navigation Co.[2]

Turbine Driven.		*Reciprocating Engines.*					
"**Brighton.**"	"**Dieppe.**"	*Arundel.*	"**Loongana.**"	"**Lhassa.**"	"**Linga.**"	"**Lama.**"	"**Lunka.**"
1903	Tenders, August 8, 1904 Launch, April 6/05	*April 25, 1900*	...	...	...	Dec. 8, 1904	1904
Aug. 1903	July 6/05	...	Aug. 1904	...	Oct. 1904	...	...
Denny	Fairfield	*Denny & Bros.*	Denny	Denny	Denny	Denny	Denny
Dumbarton	Govan	*Dumbarton*	Dumbarton	Dumbarton	...	...	...
282ft.	274ft.	*277ft.*	300ft.	275ft.	275ft.	275ft.	...
37ft.	34ft. 8in.	...	43ft.	44ft.	44ft.	44ft.	...
15ft. 2½in.	14ft. 6in.	...	...	...	...	...	...
...	...	...	18ft.	25ft.	25ft.	...	...
22ft.	...	...	...	...	...	...	...
9ft.	9½ft.	...	12½ft.	...	...	...	...
10	...	...	...	...	...	...	...
1000	...	*900*	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
1130	1600	*1060 tons*	2440 tons	2200	2200	...	...
...	...	...	...	...	...	...	...
21½	21½	...	20·14	18·09	18·05	...	...
12	...	...	...	...	...	...	...
64 knots	...	...	...	...	...	...	...
2 hours 59 minutes	...	...	30½ days	...	...	...	...
20	...	...	15	...	...	...	...
7000	7000	...	6000	4000	4000	...	...
Denny	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
4	4	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
150	150	...	150	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...

[1] The "**Maheno**," 5500 tons, 7000 H.P., 17½ knots, 3 turbine-driven propellers, has been added to the U.S.S. Co. of N.Z.'s fleet. 400 feet long, 50 feet beam, 32½ feet deep. "Maheno" accommodates 223 first-class, 116 second-class, 60 third-class passengers. Trials Sept. 29, 1905, with 3000 tons dead weight, 17·5 knots with all boilers. It has 2 double-ended, 2 single-ended boilers, Howden's forced draught.

[2] The "**Bingera**" and two sister ships 2300 tons, 6000 H.-P., 18 knots, 3 turbine-driven propellers added to the B.I.S.N. Co.'s fleet. 300 feet long, built by Messrs Workman-Clark.

	Turbine Steamers.			*Reciprocating Engine Steamer.*
Name of Vessel	"Queen."	"Onward."	"Invicta."	*Victoria.*
Superheaters	None	...	...	...
Shafts :—				
Number	3	3	3	3
Diameter	7ins.	...	...	...
Weight	...	..	...	...
Propellers, total	5 [1]	...	...	...
Number of blades each	3	3	...	...
Diameter	42in., 27in., 27in.	72in.	...	...
Pitch	...	...	...	...
Steam Turbine :—				
Made by	Parsons Steam Turbine Co.	...	Denny	...
Type	...	...	Parsons	...
Number	3	3	3	...
Governors	centrifugal electrically operated throttle valve	...	...	...
High-pressure Turbines :—				
Number	1	...	...	...
Position	centre	...	...	...
Revolutions per minute	480	440	...	.
Expansion	5-fold	...	...	...
Low-pressure Turbines :—				
Number	2	...	...	...
Position	each side	...	...	...
Revolutions per minute	500	...	...	...
Expansion	25-fold	...	...	...
Total ratio of expansion	125-fold	...	...	...
Go-astern Turbines :—				
Number	2	...	...	...
Position	each side	...	...	...
Revolutions per minute	...	...	...	...
Rated horse-power condensing	...	...	...	.
Rated H.-p. non-condensing	...	...	...	...
For comparison : Reciprocating Engines :				
Piston Engines :—				
Maker	...	...	...	...
Type	...	...	...	...
Number	...	...	...	...
Cylinders diameters	...	...	...	...

[1] "Queen" has only three propellers now, 72ins. and 67ins. diam.

Turbine Driven.		*Reciprocating Engines.*					
"Brighton."	"Dieppe."	*Arundel.*	"Loongana."	"Lhassa."	"Linga."	"Lama."	"Lunka."
...	...	...	...	...	...	...	...
3	3	...	3	3	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
3	3	...	3	3	...	...	..
66in., 67½in., 67½in.	60in.	...	68in.	...	...	...	...
72in., 70in., 70in.	...	..	...	...	...	...	...
Parsons Marine Steam Turbine Co., Ltd., Wallsend	Fairfield Co.	...	Parsons	...	Parsons	Denny	Denny
...	...	...	...	...	...	Parsons	Parsons
...	...	...	...	...	...	...	...
centrifugal	...	...	...	..	...	...	...
1	1	...	...	...	..	...	...
centre shaft	...	...	...	...	...	...	...
520	600	...	...	...	...	...	...
in trial, Sept. 1, 1903	...	...	...	...	...	...	...
2	2	...	...	...	...	...	...
each side	...	...	...	...	...	...	...
600	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
125-fold	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...
in aft end, each l. p. turbine	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	..	...	...	..	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...

	Turbine Steamers.			*Reciprocating Engine Steamer.*
Name of Vessel . . .	"Queen."	"Onward."	"Invicta."	*Victoria.*
R.p.m. full speed . .	...	...	...	...
Stroke	...	..	...	...
Rated power condensing .	...	...	...	...
Rated power non-condensing	...	...	...	...
Steam consumed . . .	...	...	...	...
Weight of steam per hour full speed	...	...	...	...
Coal per I.H.P. hour—lbs. .	1·82[1]	...	...	..
Coal burnt at full speed . .	...	...	...	...
Condenser:—				
Position	in each wing	...	...	...
Type	surface	...	...	...
Number	2	...	...	...
Surface	...	...	...	...
Power used by . . .	...	...	...	...
Air Pump and Circulating Pump:—	1 beam engine	...	...	...
Maker	...	...	...	.
Type	...	...	...	...
Vacuum maintained at full speed	...	...	...	...
Temp. of discharge at full speed	...	...	...	...
Steam per hour used at full speed	...	...	...	...
Air pump barrel diameter and stroke	...	...	...	...
Steam cylinder diameter .	...	...	...	...
Strokes per minute . .	...	...	...	...
Circulating Pump . . .	on air pump engine shaft	...	...	...
Made by	...	..	...	...
Type	...	...	...	...
Steam per hour at full speed	...	...	...	...
Weight of circulating water per unit weight of steam	...	...	...	...
Temperature suction . .	...	...	...	..
Temperature discharge .	..	...	...	...
Electric-lighting Engine:—				
Maker	.	...	...	...
Type	...	...	...	...
K.W. capacity each . .	...	...	...	.
Position	...	...	...	...

[1] "Queen" does journey in 9 minutes less time than *Victoria* and *Empress* on the same weight of coal.

Turbine Driven.		*Reciprocating Engines.*					
"Brighton."	"Dieppe."	*Arundel.*	"Loongana."	"Lhassa."	"Linga."	"Lama."	"Lunka."
...	...	...	...	...	...	...	...
...	...	...	..	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	1·8[1]	...	...	...	...	...	...
...	...	...	63 tons per day for 30½ days at 15 knots.	...	...	...	...
...	...	...	...	...	...	...	...
surface	...	...	...	...	...	...	...
2	2	...	...	...	...	...	...
between l.p. turbine and side plating	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
compound engines drive air and circulating pumps each side.	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	..	...	...	...	...
...	...	...	...	...	...	...	...
...	...	..	...	...	..	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
2 centrifugal	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	..	...
...	...	...	...	...	...	...	...
...	...	...	...	...	..	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	.	...	...	.
...	...	...	.	..	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	..

[1] In a comparison with a *Reciprocating Vessel of equal power* by Mr R. J. Walker at *Liverpool Eng. Soc.*, Feb. 1906, the "Dieppe" consumed 1·8; 1·8; 2·0 lbs. per H.P.H. *against the reciprocating vessel's 2·17; 1·8; and 1·6 lbs. per H.P.H.* at full, three-quarters, and one-third power respectively.

	Turbine Steamers.			*Reciprocating Engine Steamer.*
Name of Vessel . . .	"Queen."	"Onward."	"Invicta."	*Victoria.*
Steam Tiller:—				
Made by	Brown Bros.	...	...	...
Figures:—Crosssection showing turbines and condensers	Fig. 472	...	...	...
Illustration of vessel . .	Fig. 473	...	...	...
Feed Pumps:—				
Made by	Weir	...	...	...
Type	...	...	...	...
Number	two	...	...	...
Water cylinder diam. stroke	...	...	...	...
Steam cylinder diameter .	...	...	...	...
Capacity per hour . .	...	...	.	...
Steam consumed per hour .	...	...	...	...
Oil circulation—pressure .	...	...	...	..
,, —consumption .	infinitesimal[1]	...	...	...
Steam consumed per hour .	...	...	...	...
Weights:—				
Boilers, including water .	...	...	..	...
Turbine machinery . .	...	...	...	...
Main reciprocating engines	...	...	...	...
Shafting	...	.	..	...
Total . . .	...	...	...	...
Costs				
Test Results:—				
When firing	...	...	...	...
Guaranteed speed, knots .	...	...	21	...
Four-hour trial, knots . .	...	..	21·85	...
Mean speed on measured mile, knots	21 76	.	22·93	19·25
Speed with h.p. steam in two l.p. turbines, h.p. turbine running idle	13	...	...	...
Steam pressure at boilers per sq. in.	...	...	.	...
In h.p. receiver per sq. in. .	...	...	.	...
In l.p. turbine (mean) per sq. in.	12lbs.	...	...	...
Vacuum—inches mercury .	...	...	...	...
R.p.m. horse-power turbine .	500	...	...	...
l.p. turbine . . .	550/560	...	...	...
Reciprocating engines . .	...	...	...	...
Engine-room staff . . .	4 less than *Victoria* or *Empress*	...	...	...
Stopping:—				
From forward speed of . .	19 knots	..	...	...
Vessel brought to rest in time	67 secs.	...	...	...
Vessel brought to rest in distance	2½ lengths	...	...	...
Retardation feet per sec.[2] .	·35	...	...	...
Average superiority over paddle steamers:—				
In good weather . . .	9 minutes	...	...	...
In bad weather . . .	20 minutes	...	...	...

[1] Chairman, S.E. Ry. Co.

Turbine Driven.		*Reciprocating Engines.*					
"Brighton."	"Dieppe."	*Arundel.*	"Loongana."	"Lhassa."	"Linga."	"Lama."	"Lunka."
Brown Bros.	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
Fig. 474	...	...	...	...	...	...	...
Weir	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
6 lbs. per sq. in.	...	...	...	...	...	...	...
negligible[1]	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
520	...	...	...	...	...	...	...
600	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	Two more than in *Brighton*	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...

[1] Forced lubrication supplies tunnel bearings also, and there is water supply also. The oil consumption is negligible compared with that in the *Arundel*.

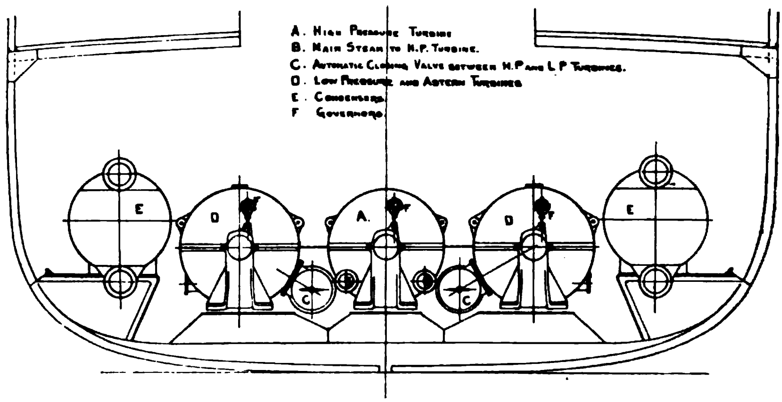


FIG. 472.—The "Queen." S.E. & C. Ry. Co. Dover–Calais.
Cross-Section of Steamer, showing Turbines and Condensers.

Service . . . . Midland Railway Co.

Route . . . . Heysham Harbour to Ireland and to Isle of Man.

	Turbine Steamers.		*Reciprocating Engines.*	
Name of Vessel	"Londonderry."	"**Manxman.**"	*Antrim.*	*Donegal.*
Date of launch . .		June 15, 1904	*Mar. 22, 1904.*	
Name of designers . .	Messrs Biles, Gray & Co., London.			
Name of builder	Wm. Denny and Bros.	Vickers, Sons, & Maxim	*John Brown & Co., Ltd.*	*Caird & Co. Ltd.*
Place	Dumbarton	Barrow	*Clydebank*	*Greenock*
Vessel's length overall .	330ft.	330ft.	*330ft.*	*330ft.*
Length between perpendicular	...	...	...	...
Beam	...	...	...	...
Breadth (moulded) . .	42ft.	43ft.	*42ft.*	*42ft.*
Depth, upper deck to keel	18ft.	18ft.	*18ft.*	*18ft.*
Depth, promenade deck to keel	25½ft	25½ft.	*25½ft.*	*25½ft.*
Draft	13ft.	13ft.	*13½ft.*	*13½ft.*
Passenger accommodation : –				
1st class	156	156	*156*	*156*
2nd class	none	...	...	...
3rd class	85	...	*85*	*85*
Displacement . . .	2400 tons	2400 tons	*2600 tons*	*2600 tons*
Gross tonnage	2086	2174	2100	1997
Net	651	629	603	594
Speed forward	22·27 knots	23 knots	*21·9 knots*	*21·9 knots*

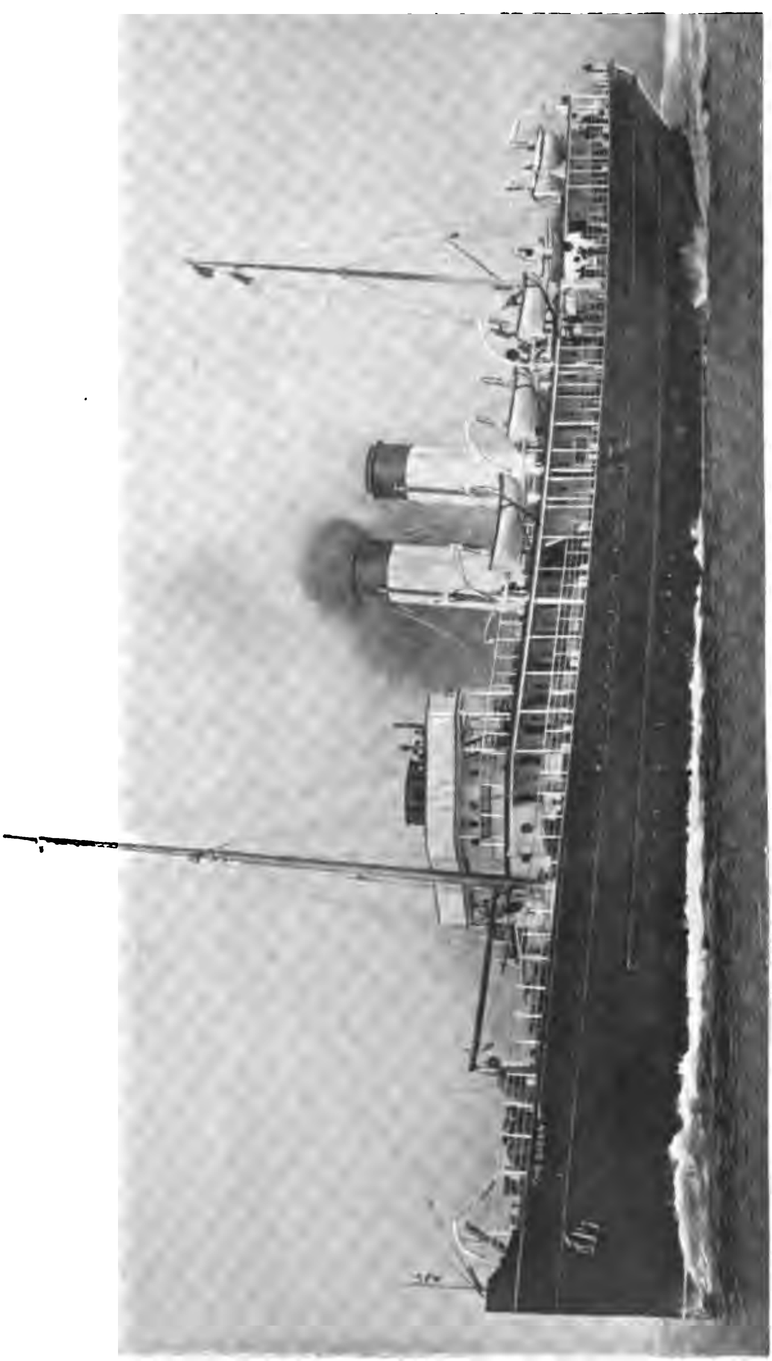


FIG. 473.—The "Queen."

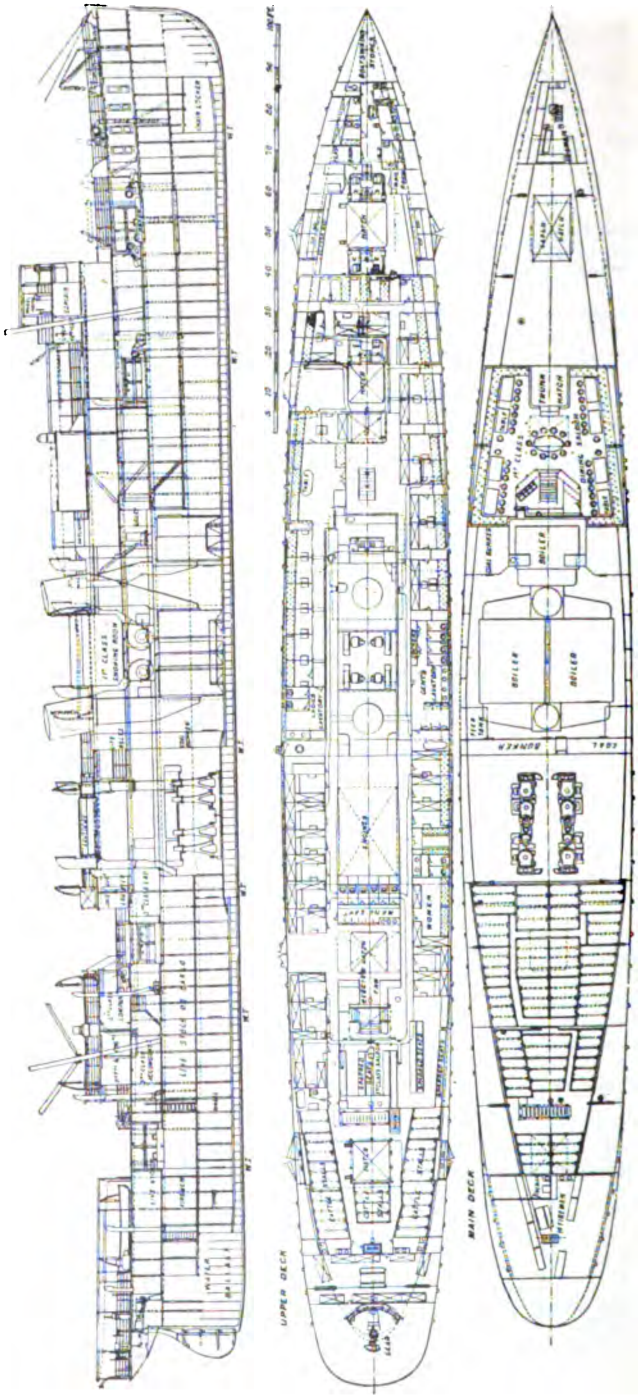
FIG. 474.—The "Brighton."

	Turbine Steamers.		*Reciprocating Engines.*	
Name of Vessel . . .	"London-derry."	"Manxman."	*Antrim.*	*Donegal.*
Boilers :—	Same equipment in each vessel.			
Total heating surface .	12,460 sq. ft.			
Total grate area . .	400 sq. ft.			
	Double-Ended.		Single-Ended.	
Number	2 ,,	and	1 ,,	
Length	22ft.		11ft. 6in.	
Diameter . .	15ft. 7in.		15ft. 7in.	
Number of furnaces .	6		3	
Diameter of furnaces .	3ft. 11in.		3ft. 11in.	
Length of grate . .	6ft. 6in.		6ft. 6in.	
Heating surface, each .	4984 sq. ft.		2493 sq. ft.	
Grate area, each . .	161 sq. ft.		80 sq. ft.	
Draught pressure (water) .	$1\frac{1}{4}$in.	1·5in.	1·1in.	
Draught produced by .	steam engines by Paul & Co., Dumbarton	steam engines by Paul & Co., Dumbarton	*electric motors Lancashire Company*	*electric motors Siemens Bros.*
Steam pressure, lbs. per sq. in.	150	200	*200*	*200*
Funnels:—				
Number	2	2	*2*	*2*
Diameter	9ft.	9ft.	*9ft.*	*9ft.*
Superheaters :—	none		*none*	
Shafts :—				
Number	3	3	*2*	*2*
Diameter of tunnel shafting	$6\frac{1}{2}$ins.	$6\frac{1}{2}$ins.	*11ins.*	*11ins.*
Diameter of propeller shafting	$7\frac{1}{4}$ and $7\frac{1}{8}$	$7\frac{1}{4}$ and $7\frac{1}{8}$	*12ins.*	*12ins.*
Propellers per shaft . .	1	1	*1*	*1*
Number of blades each .	3	3	*3*	*3*
Diametor	5ft.	centre 6ft. 2in. ; sides 5′ 7″	... *10ft. 6ins.*	*11ft.*
Pitch	4ft. 6in.	5ft. 7in. ; 5′ 0″	*13ft. 8ins.*	*13ft. 6ins.*
Steam Turbine :—				
Made by	Parsons Turbine	Marine Steam Co.	...	...
Type	compound	compound	...	...
High-pressure Turbines :—				
Number	1	1	...	...
Position	centre shaft	centre	...	...
Revolutions per minute .	650	530	...	...
Low-pressure Turbines :—				...
Number	2	2	...	...
Position	each side shaft	each side	...	...
Revolutions per minute .	750	600	...	...
Go-astern Turbines :—				
Number	2	2	...	...
Position	in back casing of each l turbine	in back casing of each l. p turbine	...	...
Revolutions per minute .	...	...	...	...
Rated h.-p. condensing .	...	...	...	...

	Turbine Steamers.		*Reciprocating Engines.*	
Name of Vessel	"London-derry."	"Manxman."	*Antrim.*	*Donegal.*
Rated h.-p. non-condensing	...	...	...	...
For comparison:—Reciprocating Engines:				
Maker	...	...	*I. Brown & Co. Clydebank*	*Caird & Co., Greenock*
Type	...	...	*Triple expans.*	*triple expans.*
Number	...	...	*2*	*2*
Cylinders diameters	...	...	*23ins., 36ins., two of 42ins.*	*23ins., 36ins., two of 42ins*
Revolutions per minute full speed	...	...	*190*	*190*
Stroke	...		*30ins.*	*30ins.*
Rated power condensing	...	...	*7600*	*7600*
Rated power non-condensing	...	...	No data available.	
Steam consumed	...	...		
Weight of steam per hour full speed	...	...		
Weight of steam per hour half speed	...	...		
Coal burned per hour (full speed)	...	...		
Main Condenser:—				
Made by	Denny	Vickers	*Brown*	*Caird*
Type	Surface	Surface	*Surface*	*Surface*
Number	2	2	*2*	*2*
Surface	3700	4200	*3700*	*3700*
"Augmenter" condenser by	none	Parsons	*none*	*none*
Surface of augmenter	...	5 per cent. of main	...	...
Steam used by augmenter	..	$1\frac{1}{2}$ per cent. of turbine's steam	...	...
Illustration	...	Fig. 486	...	...
Air Pump:—				
Maker	Weir	Paul	*Weir*	*Weir*
Type	Dry air	...	*beam*	*beam*
Supplementary dry air pump	Weir 20in. d. by 9ins. s.			
Vacuum maintained at full speed	28ins.	28·8ins.	*24·5ins.*	*25·0ins.*
Temperature of discharge at full speed	...	...	...	...
Lbs. steam per hour used at full speed	...	...	...	...
Illustration	...	..	*Fig. 492*	...
Air pump barrel diameter and stroke	14ins. × 9ins.	23ins. × 8in.	*20ins. × 16ins.*	*20ins. × 16ins.*
Steam cylinder diameter	$8\frac{1}{2}$ins.	10ins.	*$7\frac{1}{2}$ins.*	*$7\frac{1}{2}$ins.*
Strokes per minute	...	...	...	...
Circulating Pump:—				
Made by	Paul, Dumbarton	Paul, Dumbarton	*Allen, Bedford*	*Allen, Bedford*

	Turbine Steamers.		*Reciprocating Engines.*	
Name of Vessel . . .	"London-derry."	"Manxman."	*Antrim.*	*Donegal.*
Type	...	...	...	...
Steam p. hour at full speed	...	..	...	..
Weight of circulating water per unit weight of steam	..	...	...	.
Temperature suction .	...	...	...	...
,, discharge .	...	...	...	...
Electric-lighting Engine .	two turbines	two turbines	*two reciprocating*	*two reciprocating*
Maker	Parsons	De Laval	*Belliss & Morcom*	*Belliss & Morcom*
Type	...	...	...	...
K.W. capacity each .	...	...	...	...
Position	shaft tunnel	...	*engine-room*	*engine-room*
Drawings of vessel .	Figs. 475/7	Figs. 475/7	*Figs. 475/7*	*Figs 475/7*
of turbine . . .	Figs. 480/1 and 484	...	...	...
of reciprocating engines for comparison	...	...	*Figs. 478/9 and 482*	..
of boiler arrangement .	Fig. 488 to 491	...	*Figs. 488 to 491*	...
of condensing plant. .	Fig. 486	...	...	...
of slip of propeller . .	...	Table CXLI.		*Table CXLI.*
Photographs of vessel . .	...	Fig.	...	...
of engine-room . .	Figs. 485 and 487	...	...	*Fig. 483*
of turbine details . .	...	...	...	...
of condenser . . .	...	...	...	...
of air and circulating pumps	..	...	*Fig. 492*	*Fig.*
of reciprocating engines	...	...	...	*Fig. 482*
Feed Pumps :—				
Made by . .	Weir	Weir	*Weir*	*Weir*
Type	direct double act.	direct double act.	*direct double act.*	*direct double act.*
Number	2	2	*2*	*2*
Water cylinder—diameter stroke	11ins.	11ins.	*11ins.*	*11ins.*
Steam cylinder diameter .	26ins.	26ins.	*26ins.*	*26ins.*
Capacity per hour . .	...	...	*15ins.*	...
Steam consumed per hour	...	...	*6000*	...
Oil circulation . . .	two Weir	...	...	...
Steam consumed per hour	...	...	...	...
Weights :—				
Boilers, including water .	390 tons	..	*460 tons*	...
Turbine machinery . .	160 tons	...	...	..
Main reciprocating engines	...	...	*210 tons*	..
Shafting	25 tons	..	*60 tons*	..
Propellers[1]	10 ,,		*10 ,,*	
Total . . .	575 tons	...	*630 tons*	...

[1] Weights of propellers obtained by difference from total weights as stated, July 20, 1905, and partial weights in *Engineering*.



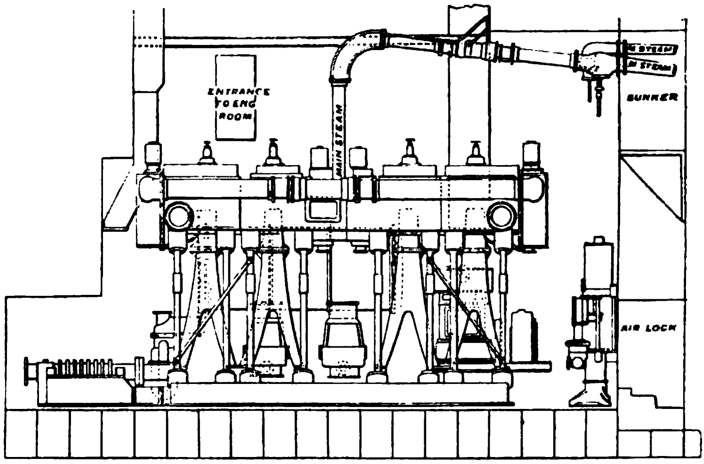
FIGS. 475 to 477.—Midland Railway Co.'s "Londonderry," "Manxman," *Antrim*, and *Donegal*.
(Messrs Biles, Gray & Co., Naval Architects, London.)

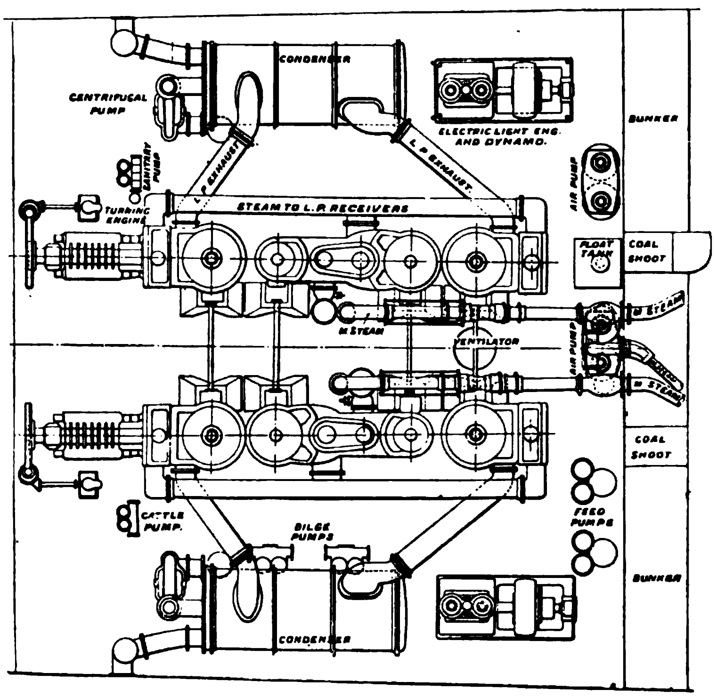
	Turbine Steamers.		*Reciprocating Engines.*	
Name of Vessel . . .	"**London-derry.**"	"**Manxman.**"	*Antrim.*	*Donegal.*
Costs, relative . . .	101½ per cent.	...	*100 per cent.*	...
Test Results :—				
When firing two double-ended boilers—				
Guaranteed speed—knots	20	20	*20*	*20*
Six-hour trial speed—knots	21·6	...	*20·6*	*20·6*
Mean speed on measured mile	21·9	...	*21·0*	*21·0*
When firing all boilers—				
Mean speed on measured mile—knots	22·36	23·12	*21·9*	*21·9*
Steam pressure at boilers per sq. in.	150 lbs.	200 lbs.	*200lbs.*	*200lbs.*
In h.p. receiver per sq. in.	135 lbs.	180 lbs.	...	...
In l.p. receiver ,,	12 lbs.	19 lbs.	...	...
Vacuum, inches mercury .	28	28·5	*24·5*	*25·0*
Revolutions per minute h.p. turbine	670	520	...	...
Revolutions per minute l.p. turbine	750	590	...	...
Revolutions per minute reciprocating engines	...	...	*191*	*191*
Relative water consumption at same speed (measured by counting feed-pump strokes)[1]	94 per cent.	90 per cent.	*100 per cent.*	...
Economy attributable to turbines	2 per cent.	...	...	...
Economy attributable to less displacement	4 per cent.	...	...	...
	100 per cent.	...	...	...
Lbs. of water per hour				
at 14 knots	45,000	45,000	*45,000*	*45,000*
17	61,000	58,000	*67,000*	*67,000*
20	89,000	83,000	*97,000*	*97,000*
22	136,000	125,000	...	...
23	...	173,000	...	...
Coal[2] *consumed under easy steaming conditions with 3 boilers in use:*				
Number of passages between Heysham and Belfast	90	68	*77*	*81*
Coal per passage. . .	36·1 tons	39·6 tons	*36·7 tons*	*37·2 tons*
Time at full speed . .	5·81 hrs.	5·35 hrs.	*5·78*	*6·07 hrs.*
,, ,, as a percentage of total time under steam	85·7 per cent.	79·5 per cent.	*85·5*	*87·7 per cent.*

1 Method found thoroughly reliable, when compared with direct measurement by tank, by the Cunard Turbine Commission.

2 *Proceedings Inst. Naval Architects*, July 20, 1905.

Fig. 478.



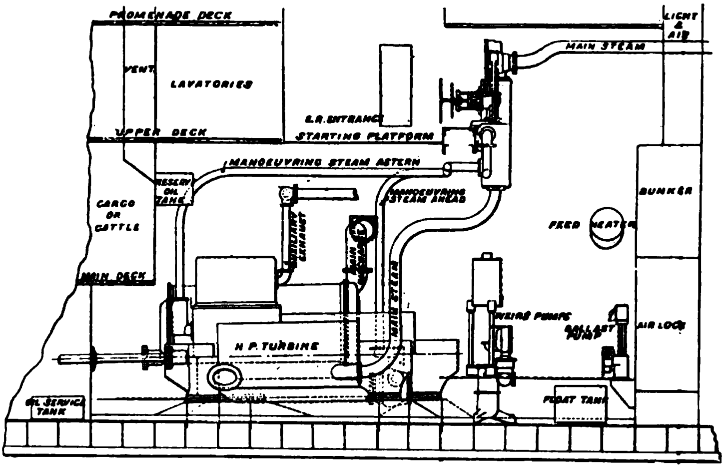


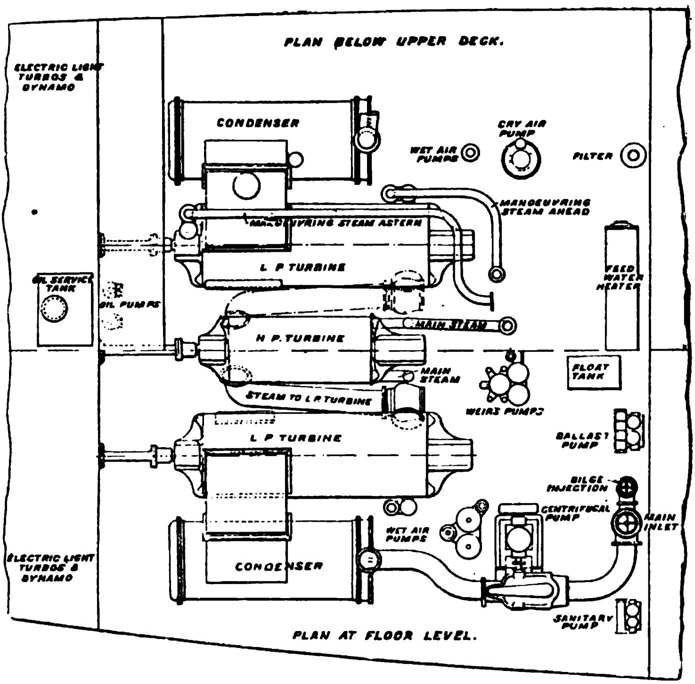
ENGINE ROOM.

Fig. 479.

Figs. 478 and 479.—Midland Ry. Co.'s S.S. *Antrim* and *Donegal*.

FIG. 480.

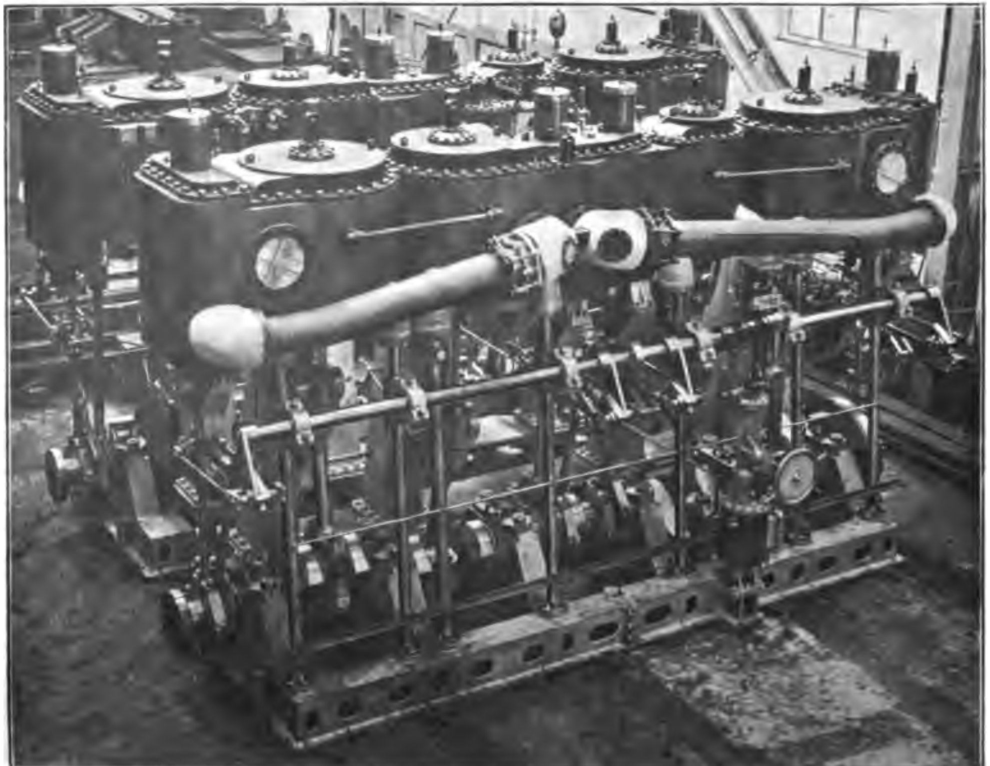




TURBINE ROOM.

FIG. 481.

FIGS. 480 and 481.—Midland Ry. Co.'s S.S. "Londonderry" and "Manxman."



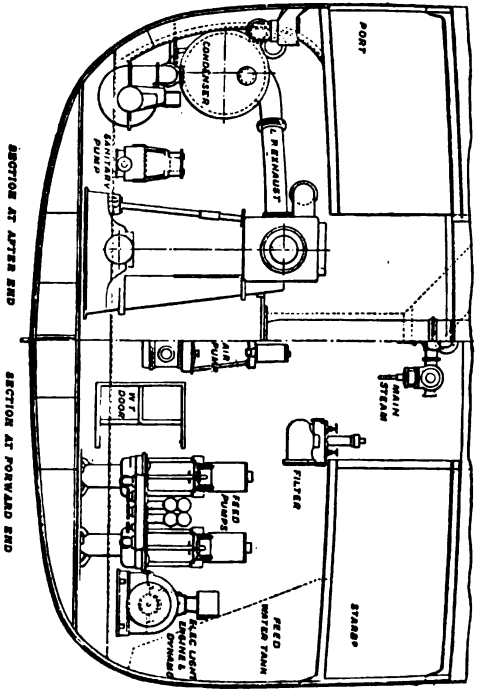


FIG 482.—Engine Room.

FIGS. 482 and 483.—*Reciprocating Engines of Midland Ry. Co.'s Steamer* "Donegal," *and Cross-Section of Engine-Room.*

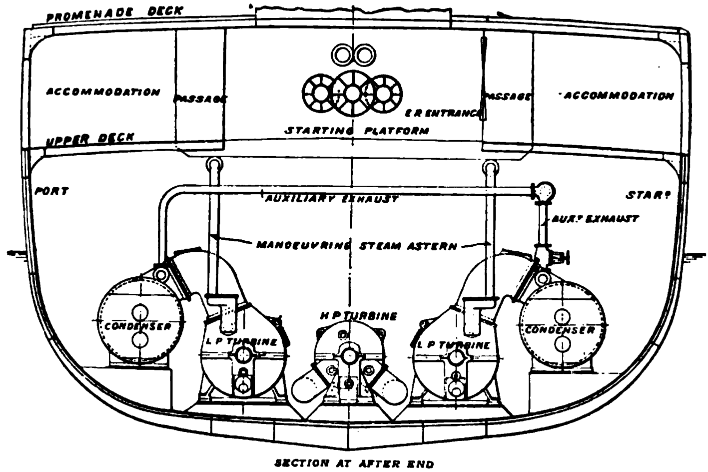
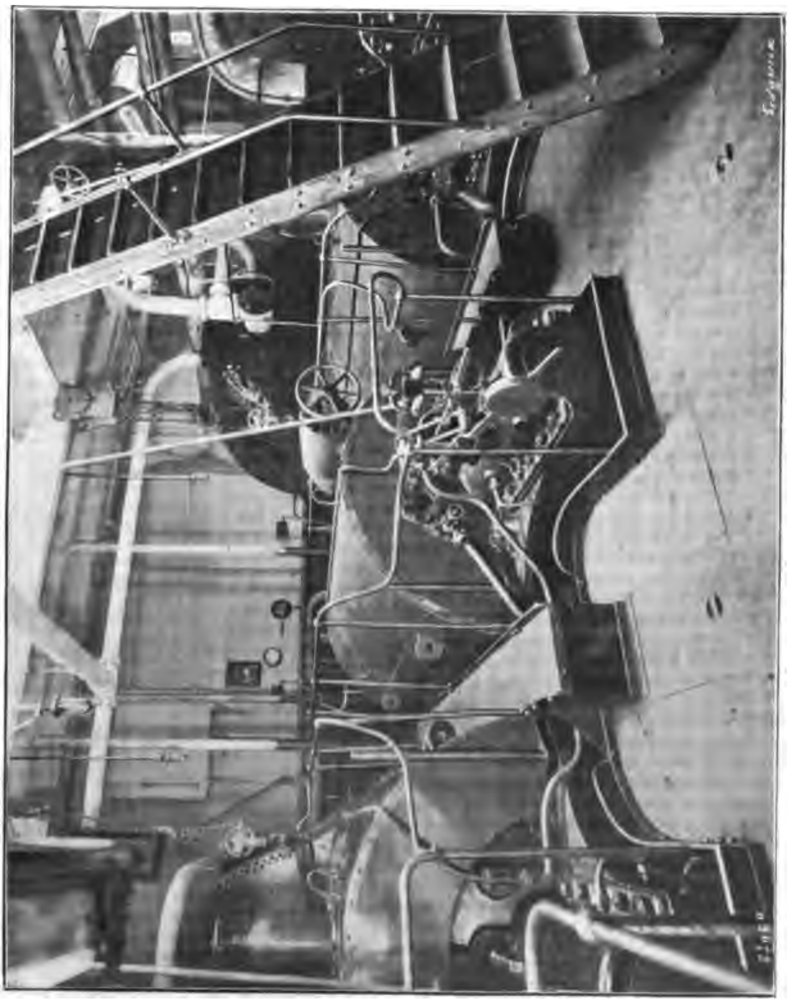


FIG. 484.—Turbine Room.



FIGS. 484 and 485.—Steamer "**Manxman.**" Turbine-Room seen from starboard side, and Cross-Section.

By the courtesy of Mr William Gray of Messrs Biles, Gray & Co., who designed these vessels, many details not previously published are included above.

Our acknowledgments for illustrations are due to the Institution of Naval Architects, the Midland Railway Company's Officials, and the Editors of *Engineering*.

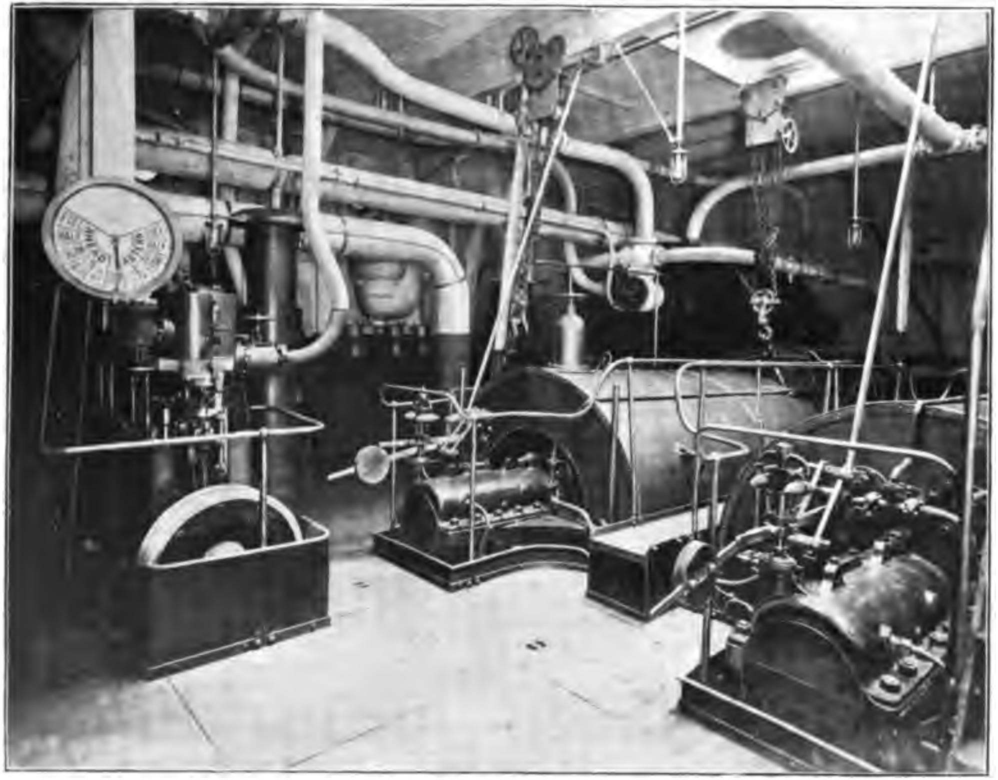
TABLE CXLI.—REVOLUTIONS AND SLIPS OF TURBINE AND RECIPROCATING ENGINED SHIP.

Speed.	"Manxman."		*Reciprocating Engined Ship.*	
	Mean Revolutions per Minute.	Percentage Slip.	Mean Revolutions per Minute.	Percentage Slip.
15 knots	335		...	
		15		...
16 "	365		*135*	
		16		*16+*
17 "	390		*142*	
		17		*16*
18 "	420		*160*	
		18		*15+*
19 "	450		*170*	
		19		*15*
20 "	480		*175*	
		20		*14+*
21 "	500		*180*	
		21		*13+*
22 "	530			
		22	...	...
23 "	580			
		24	...	...

Position of Starting Platforms.—In the "Manxman" the starting platform is on the same level as the turbines; in the "Londonderry" it is on the level of the deck above, and the effect is not quite so satisfactory in respect of light, or overseeing by the engineer-in-charge.

Fig 485 on the previous page is reproduced from a photographic view looking towards the port side of the ship, and shows all three turbines. The high-pressure turbine is in the centre, and the mechanism connected with the governing is clearly indicated.

Governing Turbines.—The governors, which are mounted on each shaft, only come into operation in the event of a breakdown, or of excessive racing of the propeller shafts. The system of centrifugal governor generally adopted in Parsons turbines moves a small relay plunger which regulates the steam admitted to a



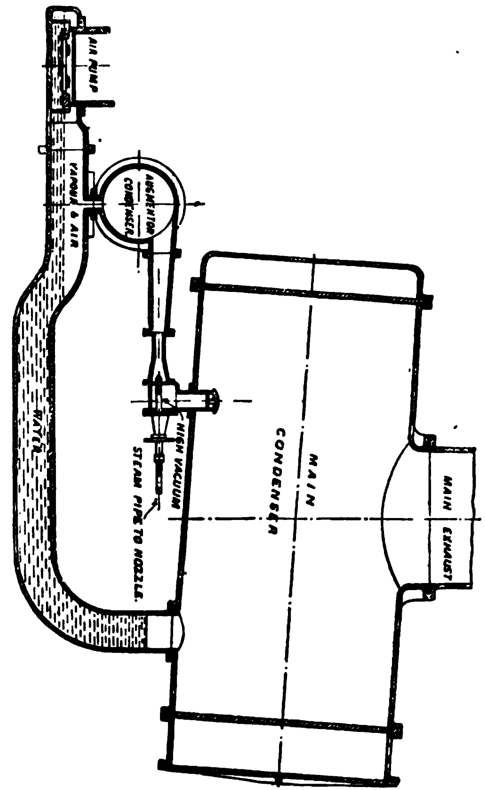
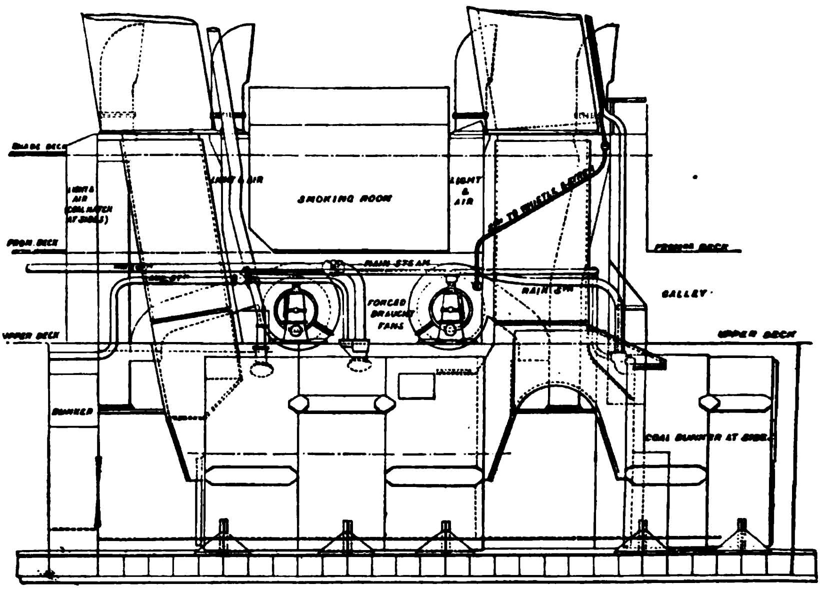
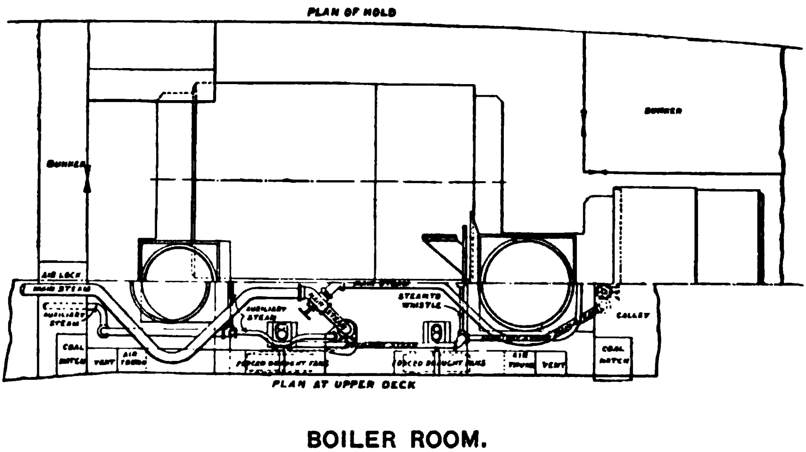


FIG. 486.

FIGS. 486 and 487.—Turbine Steamer "Manxman." Turbine-Room seen from port side, and Condensers.

FIG. 488.



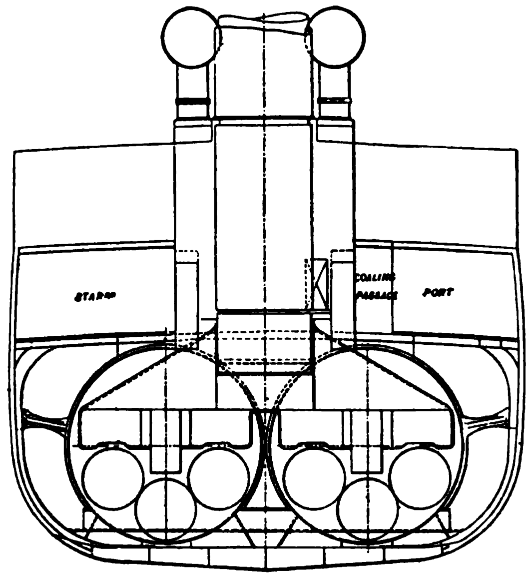


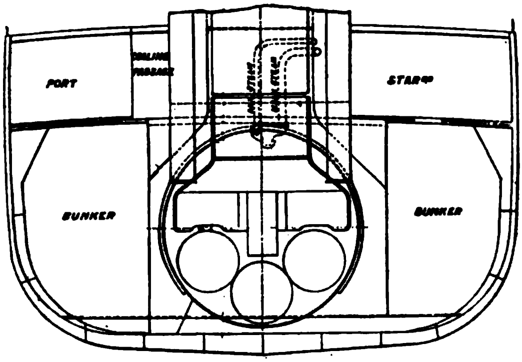
BOILER ROOM.

FIG. 489.

FIGS. 488 and 489.—Midland Railway Co.'s Four Steamers "**Londonderry**," "**Manxman**," *Antrim*, and *Donegal*.

Fig. 490.





BOILER ROOM.

Fig. 491.

Figs. 490 and 491.—Midland Railway Co.'s Four Steamers "Londonderry," "Manxman," *Antrim*, and *Donegal*.

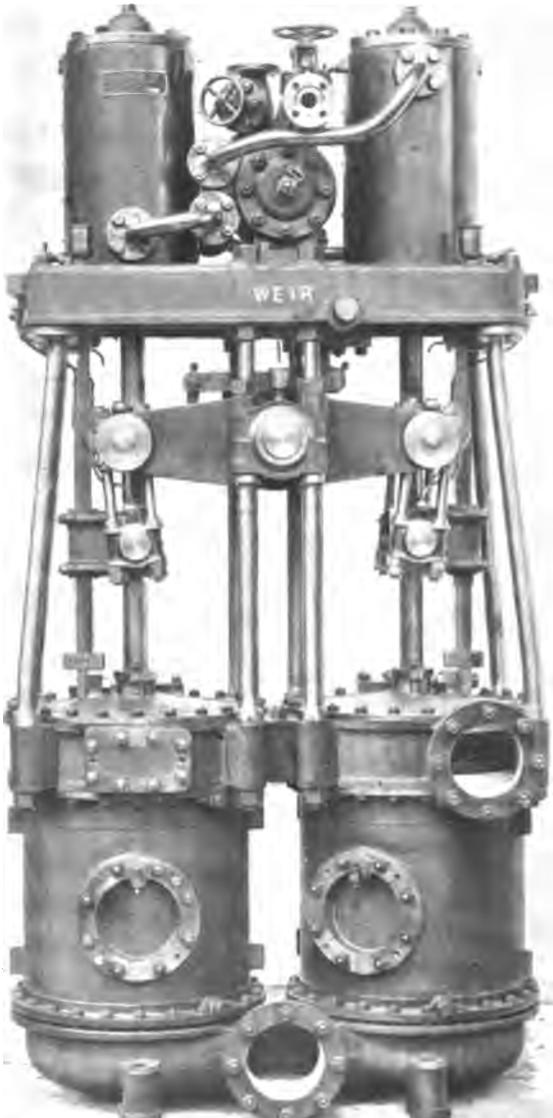


FIG. 492.—Weir Beam Air Pump.

relay, which in turn actuates the main throttle valve, generally of the balanced double-beat type. The exhaust from the steam relay is utilised for the steam packing of the end glands. Thus the governor, having only to move the small plunger, has very little work to do, and therefore can be made very sensitive. The sensitiveness is still further increased by keeping the whole governor gear in slight movement by connecting one of the pivots of the levers with a cam. These movements are so rapid as not to affect the even turning moment of the turbine.

Steam By-pass to Intermediate Stage.—On the top of the high-pressure turbine is the by-pass valve which is used for the admission of steam at full pressure to an intermediate stage on the high-pressure turbine, so as to increase the power—at the expense, however, of economy. During the trials of the *Manxman* no such high-pressure steam was admitted at the intermediate stage, the turbines being worked to the full degree of expansion.

Steam to Glands, etc.—The pipes for the admission of steam to the glands, as well as the smaller pipes for oil and water service, are also shown. The passage-way between the turbines leads to the after-end of the engine-room, where the oil pumps are placed, as well as to the tunnels.

Some Test Results.—Two other trials were made over the measured mile, and the results, subsequent to the official test, may be given:—

TABLE CXLII.—UNOFFICIAL TEST OF MIDLAND RAILWAY CO.'S STEAMER "MANXMAN."

Mean speed of two runs	23·141 knots
Boiler pressure per sq. in.	192 lb.
Steam in high-pressure turbine	180 „
„ low-pressure turbine, port	20 lb.
„ „ „ starboard	20 „
[1] Vacuum in condenser, port	28·25 in.
„ „ starboard	28·4 „
Revolutions per minute, high-pressure turbine	533
„ „ low „	609
Temperature of feed-water leaving heater	180 deg. Fahr.
Air-pressure in stokehold	1·5 in.

TABLE CXLIII.—OFFICIAL TEST OF MIDLAND RAILWAY CO.'S STEAMER "MANXMAN."

Mean speed	22·65 knots
Revolutions, high-pressure turbine	520
Revolutions, low-pressure turbine	590
[1] Vacuum, port	28·6 in.
Vacuum, starboard	28·4 „

[1] The vacuum was read by a mercury column connected to the main condenser discharge.

Augmenter Condenser.—The high vacuum was maintained throughout, frequently as high as 29 in., by the use of a "vacuum augmenter." In it the air pumps are placed about 3 ft. below the bottom of the condenser (Fig. 486, p. 705). From near the bottom a pipe is led to an auxiliary condenser, about one-twentieth the cooling surface of the main condenser, and in a contracted portion of this pipe a small steam jet is placed, which acts in the same way as a steam exhauster, or the jet in the funnel of a locomotive, and sucks nearly all the residual air and vapour from the condenser, and delivers it to the air pumps. A water seal is provided, as shown in Fig 486, to prevent the air and vapour returning to the condenser. Thus, if there is a vacuum of 27½ in. to 28 in. in the condenser, there may be only about 26 in. in the air pump, which therefore need only be of small size, the jet compressing the air and vapour from the condenser to about half of its original volume. The small quantity of steam from this steam jet, which is only about 1½ per cent. of that used by the turbine at full load, together with the air extracted, is cooled down and condensed by the auxiliary condenser, which is generally supplied with water in parallel with the main condenser. Condensation in a condenser takes place much more rapidly and effectually if the air is thoroughly extracted than if there is much air present.

Service . . . . Allan Line S.S. Co., Ltd.
Route . . . . Liverpool to Canada.

	Pioneer Turbine Vessels for Ocean Service.		*Reciprocating Engines.*	
Name of Vessel . . .	"Victorian."	"Virginian."	*Tunisian.*	*Bavarian.*
Keel laid	Oct. 1903	...	...	..
Date of launch . . .	Aug. 25, '04	Dec. 22, '04	*Jan. 17, 1900*	*1889*
Maiden voyage . . .	March 23, '05	Apr. 6, '05	...	...
Name of builder . . .	Workman, Clark & Co.	Alex. Stephen & Son	*Alex. Stephen & Son*	*Denny*
Place	Belfast	Linthouse on Clyde	...	*Dumbarton*
Vessel's length overall .	540ft.	540ft.	*520ft.*	*520ft.*
Beam	60ft.	60ft.	*59*	*59*
Depth	40ft. 6in.	41ft.	*43ft.*	*43ft.*
Bulkhead compartments . .	11	11	...	...
Water-tight spaces, total .	20	20	...	...
Draught	27½ft.	29½ft.	...	...
Passenger accommodation . .	1650	1650	...	...
1st class	470	470	*200*	*162*
2nd class	240	240	*260*	*136*
3rd class	940	940	...	*200*

	Pioneer Turbine Vessels for Ocean Service.		*Reciprocating Engines.*	
Name of Vessel . . .	"Victorian."	"Virginian."	*Tunisian.*	*Bavarian.*
Gross tonnage . . .	12,000	12,000	...	...
Displacement . . .	...	11,200	*10,000*	*10,000* (?)
Speed, knots forward .	19½	19½	...	*16*
Speed per hour astern .	...	...	...	*14*
Length of journey . .	2530	...	...	...
Best day's run 1st voyage	383	403	...	*406*
Average running speed :—	14¼	17	*15*	...
Liverpool to Halifax .	7 days 23 hrs.	6 days 18 hrs.	...	...
[1] Moville to Cape Race, 1802 miles	4 days 13 hrs.	4 days 6 hrs.	...	...
Horse-power, I.H.P. . .	12,000	12,000	...	*9840*
Boilers	...	2	...	...
Maker	Workman Clark	Stephen	*Stephen*	*Denny & Co.*
Type	Single-ended	Single-ended	*Single-ended*	...
Number installed . .	9	9	*7*	*7*
Rated capacity (lbs. per hour)	...	17ft. dia. × 12ft.	...	...
Heating surface, total .	31,000	30,800 sq. ft.	...	...
Grate area . . .	797	726 sq. ft.	...	...
Draught pressure (water)	3¼in.	...	...	...
Steam pressure—lbs. per sq. in.	180	180	...	...
Funnels :—				
Number	1	1	...	*1*
Dimensions . . .	18ft. × 13ft. 6in.	...	...	*14ft. diam.*
Superheaters	none	...	...	...
Shafts :—				
Number	3	3	*2*	*2*
Diameter . . .	11in.	...	...	*15in.*
Weight	...	...	...	...
Propellers per shaft .	1 (Fig. 516)	...	...	*2*
Number of blades each .	3	...	...	*2*
Diameter . . .	7ft. 6in. (new)	8ft.	...	*16ft. 6in.*
Steam Turbine :—				
Made by	Workman Clark	Parsons Marine S.T. Co.	...	...
Type	Parsons	...	...	...
Number	3	3	...	...
Governor	Parsons	...	...	...
Number of separate pieces in turbines	1,500,000	...	...	...
High-pressure Turbines :—				
Number	1	1	...	...
Position	Centre shaft	Centre	...	...
Revolutions per minute .	260/300	270/300	...	...
Low-pressure Turbines :—				
Number	2	2	...	...
Position	Side shafts	Side shafts	...	...
Revolutions per minute .	260/300	...	...	...
Go-astern Turbines :—				
Number	2	2	...	...
Position	Side shafts	Side shafts	...	...
Revolutions per minute .	160	...	...	...

[1] Record of "Campania," Queenstown to New York, 2900 miles, is 5 days 7 hours 23 min. "Victorian, best run, Moville to Rimouski 6 days, average 16·4 knots, 205 tons per day. Turbine blade clearance reduced and new propellers fitted, 1906.

	Pioneer Turbine Vessels for Ocean Service.		*Reciprocating Engines.*	
Name of Vessel . . .	"**Victorian.**"	"**Virginian.**"	***Tunisian.***	***Bavarian.***
Rated h.-p. condensing .	...	...	...	...
Rated h.-p. non-condensing	...	...	..	...
For comparison: Reciprocating Engines:	...	...	...	...
Piston Engines:—				
Maker	...	...	*Stephen*	*Denny*
Type	...	...	*Triple Exp.*	*Triple*
Number	...	...	*2*	*2*
Cylinders diameters .	...	...	...	...
R.p.m. full speed . .	...	...	...	*86*
Stroke	...	...	...	..
Rated power condensing .	...	...	...	*9840 I.H.P.*
Rated power non-condensing	...	...	...	...
Steam consumed . .	...	...	...	...
Weight of steam per hour full speed	...	...	.	...
Weight of steam per hour half speed	...	...	...	...
Coal consumed per hour (full speed)	8·3	...	...	...
Condenser:—				
Made by	W. C. & Co.	...	...	*Denny*
Type	Horiz. tubular	...	...	*Horiz. tubular*
Number	2	...	...	*2*
Surface	17,000 sq. ft.	...	...	...
Surface of 'augmenter' condenser	...	...	...	...
				...
Power used by 'augmenter' condenser	...	...	...	...
Air Pump:—	Fig. 492			
Maker	Weir	...	...	...
Type	Beam	...	...	*Off levers*
Vacuum maintained at full speed	28in.	...	...	*26*
Temperature of discharge at full speed	80	..	...	...
Steam per hour used at full speed	...	...	...	...
Air pump barrel diameter and stroke	31in. × 21in.	...	...	...
Steam cylinder diameter .	11in. × 21in.	...	...	...
Strokes per minute . .	...	...	...	...
Circulating Pump:—	20in.			
Made by	Allen	...	..	*Gwynn*
Type	Centrifugal	...	...	*Centrifugal*
Steam per hour at full speed	...	...	...	...
Weight of circulating water per unit weight of steam	...	...	...	...
Temperature suction .	50	...	...	...
,, discharge .	70	...	...	...
Electric-lighting Engine:—				
Maker	Belliss	...	...	*Belliss*
Type	Enclosed	...	...	*Enclosed*

	Pioneer Turbine Vessels for Ocean Service.		Reciprocating Engines.	
Name of Vessel . . .	"Victorian."	"Virginian."	*Tunisian.*	*Bavarian.*
K. W. capacity each .	...	...	...	...
Position	'Tween decks	...	...	*Bottom platform*
Telegraph system and printing outfit	Marconi	...	...	*Marconi*
Illustration of vessel .	Fig. 493	...	...	...
Illustration of turbine details	Fig. 494, 515	...	...	...
Illustration of condensing plant	...	...	...	...
Feed Pumps :—	...	...	...	..
Made by . . .	Weir	...	...	*Weir*
Type	Vertical	...	...	*Vertical*
Number	2	...	...	*2*
Water cylinder diam. stroke	14in.	...	...	...
Steam cylinder diameter .	19in. × 30in.	...	...	...
Capacity per hour . .	11 strokes per min.	...	...	...
Steam consumed per hour	...	...	...	...
Oil circulation :—				
Steam consumed per hour	...	...	...	...
Weights :—				
Boilers, including water .	...	...[3]	...	...
Turbine machinery . .	...[1]	...	...	...
Main reciprocating engines	...	...	...	...
Shafting	...	...	...	...
Total . . .	...	...	...	...
Costs	...	...	...	...
Test Results :—				
Number of boilers in use .	8	...	...	...
Guaranteed speed, knots per hour	17	...	...	...
Six hour trial speed .	18·5	...	...	...
Mean speed on measured mile	19	...	*17*	*17·95*
Maximum speed on measured mile	19½[3]	...	...	...
R.p.m. of turbine . .	260[2] (298)	...	...	...
When firing all boilers	...	...	...	...
Guaranteed speed . .	17	...	...	...
Mean speed on measured mile	19	...	...	...
Steam pressure at boilers per sq. in.	180	...	...	...
In h.p. receiver . .	170	...	...	..
In l.p receiver . .	25	...	...	...
Vacuum, inches mercury .	28	...	...	...
Revolutions per minute h.p. turbine	297	...	...	...
Revolutions per minute l.p. turbine	300	...	...	...
R. p.m. reciprocating engines	None	...	...	...

[1] The l.p. turbine weighs 78 tons. [2] This speed and revolutions per minute with (estimated) 12,000 H.P. on March 16th, 1905, off Skelmorlie. Other tests made on Clyde, March 20th, 1906 (bottom not cleaned before trials after lying up 3 months), and included here with data and photos on p. 778, Figs. 515 and 516, by courtesy of Chief Engineer, J. W. Hendry.

[3] 400 tons weight saved by turbines. J. H. Biles, LL.D., British Association, 1905.

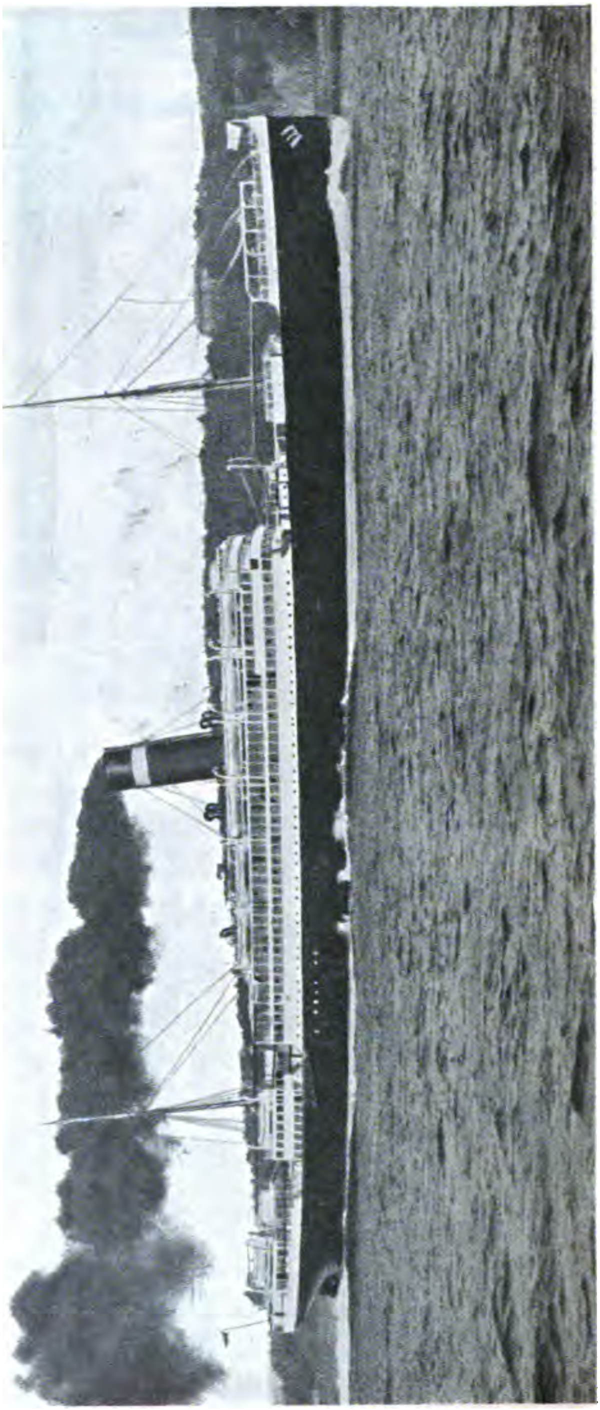


FIG. 493.—Allan Line Turbine Steamers "Virginian" and "Victorian." Length 540 Ft., Beam 60 Ft., 19·5 Knots.

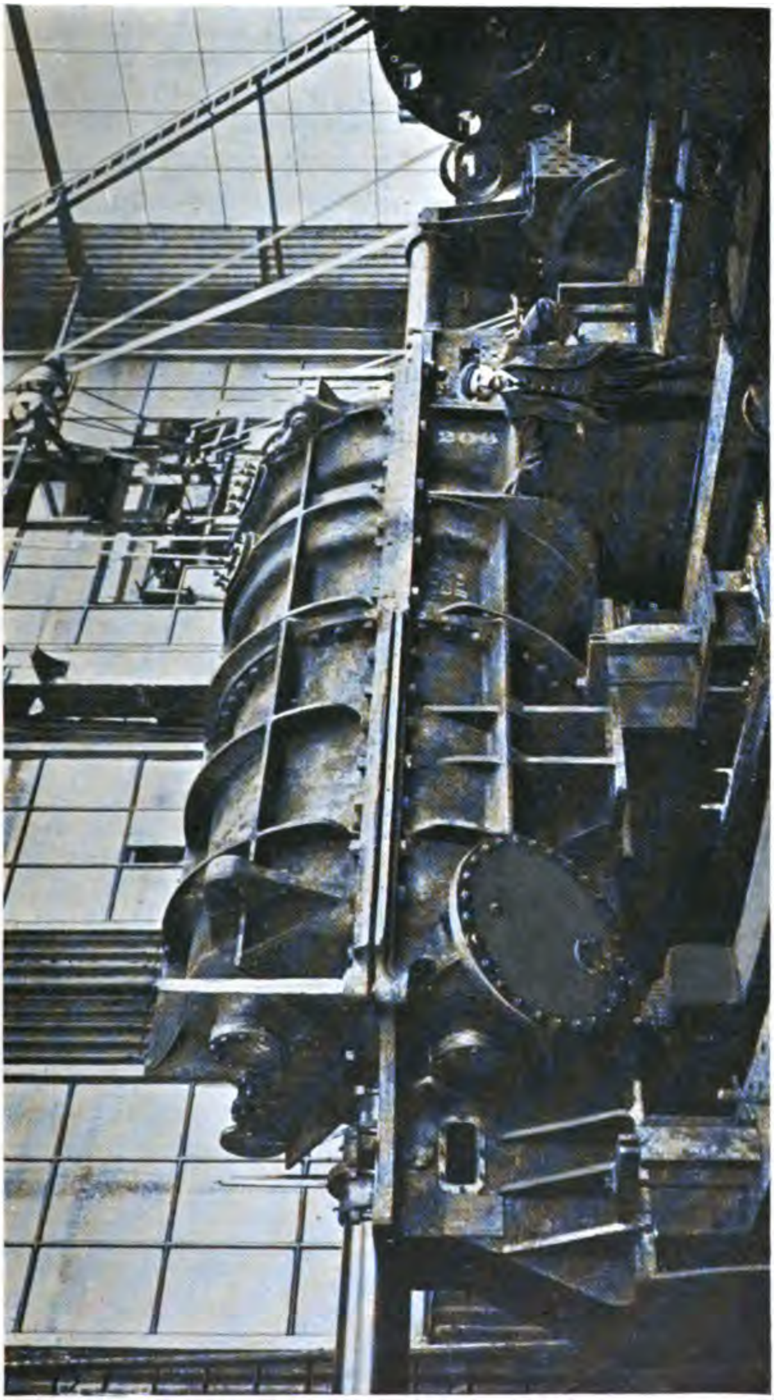


FIG. 494.—Turbine Casing for the "Victorian." Allan Line. (W. O. Wilkins, *Turbine Steamers*.)

Service . . . . Cunard S.S. Co.
Route . . . . Liverpool to New York and Boston.
Type . . . . Mercantile Cruisers.

	Turbine Steamers.				*Reciprocating*	
Name of Vessel . .	"Carmania."	"Susitania."	"Mauritania."	Ordered July 1905.	*Caronia.*[1]	*Campania and Lucania.*
Date of laying keel plate .	May 17, 1904	..	...	...	*Sept. 21, 1903*	...
Date of launch . .	Feb. 21, 1905	...	...	...	*July 13, 1904*	...
Date of completion . .	Nov. 1905	1906	1906	End 1907	*Jan. 23, 1905*	*1893*
Name of builder . .	John Brown & Co.	John Brown & Co.	Swan & Hunter and Wigham Richardson.	John Brown & Co.	*John Brown & Co.*	...
Place	Clydebank	Clydebank	Wallsend	Clydebank	*Clydebank*	
Vessel's length overall .	672½ft.	785ft.	785ft.	780ft.	*678ft.*	*625ft.*
Between perpendicular	650	760	...	...	*650*	*600*
Breadth . . .	72½ft.	88ft.	88ft.	...	*72½ft.*	*65½ft.*
Including rolling chocks	...	...	...	...	...	...
Depth moulded . .	52ft.	60ft.	60ft	...	*Shelter d. 52ft. Boat deck 80 ft.*	*41½ft.*
,, keel to roof navig. bridge . .	90ft.	...	...	...	...	...
,, keel to funnel top .	144ft.	...	...	...	...	.
,, ,, mast top .	205ft.	...	...	... .	...	...
Boat deck . . .	80	...	...	...	*97*	...
Draught . . .	33½ft.	33 or 34ft.	...	...	*33ft.*	*25ft.*
Passenger accommodation and crew	3100	...	...	...	*3200*	...
1st class . . .	300	...	...	..	*300*	*600*
2nd ,, . . .	350	...	...	...	*350*	*400*
3rd ,, . . .	1000	...	...	...	*1000*	*700*
Steerage . . .	1000	...	...	...	*1000*	...
Officers and crew . .	450	...	...	...	*550*	...
Gross tonnage . . .	19,520	...	...	...	*21,000*	*12,950 and 12,9[illegible]*
Displacement . . .	30,900 tons	30,000	30,000	To be largest ship ever built	*31,200 tons*	*18,000 tons*
Speed forward . .	21 knots	25 knots	25 knots	...	*19·5*	...
,, astern . . .	...	...	...	...	...	..
Length of journey . .	...	...	...	...	...	..

[1] "Caronia" equal to the "Saxonia," tested by Navy Boiler Committee, *Engineering*, 725, Dec. 1st, 1906.
13·4 lbs. steam per I.H.P.H.
11·3 ,, ,, ,, 1 lb. coal.
1·19 ,, coal ,, I.H.P.H.

	TURBINE STEAMERS.				*Reciprocating.*	
Name of Vessel	"Carmania."	"Susitania."	"Mauritania."	Ordered July 1905.	*Caronia.*	*Campania and Lucania.*
Average running speed	18 knots	25 knots	25 knots	...	*18*	*22 knots*
Quickest run Queenstown and New York	6½ days estimated	...	...	... ...	*7 days estimated*	*5 d. 7 hr. 23 m.*
Horse-power I.H.P.	21,000 to 22,700	75,000 estimated	75,000 estimated	60,000 estimated	*21,000 to 22,700*	*26,000 to 30,000*
Boilers:—						
Maker	...	...	...	...	...	...
Type	...	...	...	...	...	...
Number installed	8 double-ended 5 single-ended	25	25	...	*8 double-ended 5 single-ended*	*12 double-ended single-ended*
Furnace diameter	20ft	...	...	...	...	...
Rated capacity (lbs. per hour)	...	...	...	...	...	...
Heating surface, total	49,300 sq. ft.	...	...	...	...	*82,000 sq. ft.*
Grate area	1200 sq. ft.	...	...	...	...	*2630 sq. ft.*
Draught pressure (water)	Howden's	...	...	...	...	...
Steam pressure (lbs. per sq. in.)	195	...	...	...	*210*	*165*
Funnels:—	135ft.					
Number	2	4	4	...	*2*	*2*
Diameter	...	Fig. 505—	p. 727	...	...	...
Superheaters	...	None	...	...	...	...
Propeller Shafts:—						
Number	3	4	4	4	*2*	...
Diameter	...	...	...	...	*23½*	...
Weight	..	...	...	...	...	...
Propellers per shaft:—						
Number of blades each	3	...	...	...	*4*	...
Diameter	14ft.	...	...	...	...	...
Steam Turbine:—						
Made by	J. Brown & Co.	...	...	...	...	...
Type	Parsons	...	...	...	...	...
Number	3	4	4	4	...	...
High-pressure Turbines:—						
Number	1	2	2	...	...	...
Position	Centre	Each outer shaft	same	...	...	...
Revolutions per minute	...	...	...	...	...	...
Low-pressure Turbines:—	Fig. 496	...	...	...	...	...
Number	1	2	2	.	...	...
Position	Wing	Each inner shaft	same	...	...	...
Diameter of rotor	11ft.	..	. .	...	...	...

	Turbine Steamers.				Reciprocating.	
Name of Vessel	"Carmania."	"Susitania."	"Mauritania."	Ordered July 1905.	*Caronia.*	*Campania and Lucania.*
Length of rotor	$8\frac{1}{2}$ft.	...	...	...	...	...
Revolutions per minute	...	...	...	...	...	...
Go-astern Turbines:—						
Number	1	2	2	...	...	...
Position	wing	Each inner shaft	same	...	...	...
Revolutions per minute	...	...	...	...	..	...
Rated h.-p. condensing	...	...	...	...	...	...
Rated horse-power non-condensing	...	...	...	...	...	...
For comparison: Reciprocating Engines:				Height from shaft centre, 30ft. Height from bed, 36ft.		
Piston Engines:—						
Maker	...	...	...	...	...	...
Type	...	...	...	...	*Quadruple Expansion*	*Triple*
Number	...	...	...	...	*2*	*2*
Cylinders diameters	...	...	...	...	*39in., 54½in., 77in., 110in.*	*37in., 37in., 79in., 98in.*
Revolutions per minute full speed	...	...	...	...	...	...
Stroke	...	...	...	...	*66in.*	*69*
Rated power condensing	...	...	...	...	*10,500*	...
Rated power non-condensing	...	...	...	...	...	...
Pressure	...	...	...	...	...	...
For both Turbines and Reciprocating Engines:						
Steam consumed	...	...	...	...	...	...
Weight of steam per hour full speed	...	...	...	...	...	...
Condenser:—						
Made by	...	...	...	...	...	...
Type	...	...	...	...	...	...
Number	...	...	...	...	...	...
Surface	32,400	...	...	...	*27,000*	...
If any 'augmenter'—						
Surface of	...	...	...	...	...	...
Power used by	...	...	...	...	...	...
Air Pump	2[1]					
Maker	Weir	...	...	...	...	...
Type	Twin	...	...	...	...	...
Vacuum maintained at full speed	...	...	...	...	...	...

[1] "Carmania" has also two double dry-air pumps 20 in. diam 7 in. stroke.

	Turbine Steamers.				*Reciprocating.*	
Name of Vessel	"Carmania."	"Susitania."	"Mauritania."	Ordered July 1905.	*Caronia.*	*Campania and Lucania.*
Temperature of discharge at full speed	...	...	...	...	...	...
Steam per hour used at full speed	...	...	...	...	...	...
Air pump barrel diameter and stroke	33in., 21in.	...	...	...	...	...
Steam cylinder diameter	12in.	...	...	...	...	...
Strokes per minute	...	...	...	...	...	...
Circulating Pump	2					
Made by	W. H. Allen	...	...	...	...	...
		...	...	...	...	...
Type	4½ft. disc. centrifugal 2 open engines, 14in. diam., 12in. S.	...	...	...	*Two centrifugal, driven by two engines each.*	...
Suction diameter	28in.	...	...	...	...	...
Steam per hour at full speed	...	...	...	...	...	...
Weight of circulating water per unit weight of steam	60	...	...	...	30	...
Temperature suction	...	...	...	...	...	...
,, discharge	...	...	...	...	...	...
Electric - lighting Engine	4	...	...	...	...	..
Maker	...	...	...	...	...	...
Type	...	...	...	...	...	...
K.W. capacity each	75 K.W.	...	...	...	...	...
Position	Orlop deck	...	...	...	...	...
Illustration of vessel	Fig. 495	505	...	...	...	...
Illustration of Turbine details	496/500	Reduced from *Engineering.*			...	...
Comparison with Reciprocating Vessel, Figs. 501/3						
Illustration of Propellers	498	...	...	...	...	...
Feed Pumps:—						
Made by	Weir	...	...	...	...	...
Type	Direct	...	...	...	...	...
Number	4 pairs	...	...	...	...	...
Water cylinder diam.	10in.	...	...	...	...	...
,, ,, stroke	24in.	...	...	...	...	...
Steam cylinder diameter	...	...	...	...	...	...
Capacity per hour	...	...	...	...	...	...
Steam consumed per hour	...	...	...	...	...	...

Fig. 495.—Cunard Line Turbine Steamer "Carmania." *Also Reciprocating Engine Steamer "Caronia."* Length 675 Ft., Breadth 72 Ft. 4 Ins., Horse-Power 21,000.

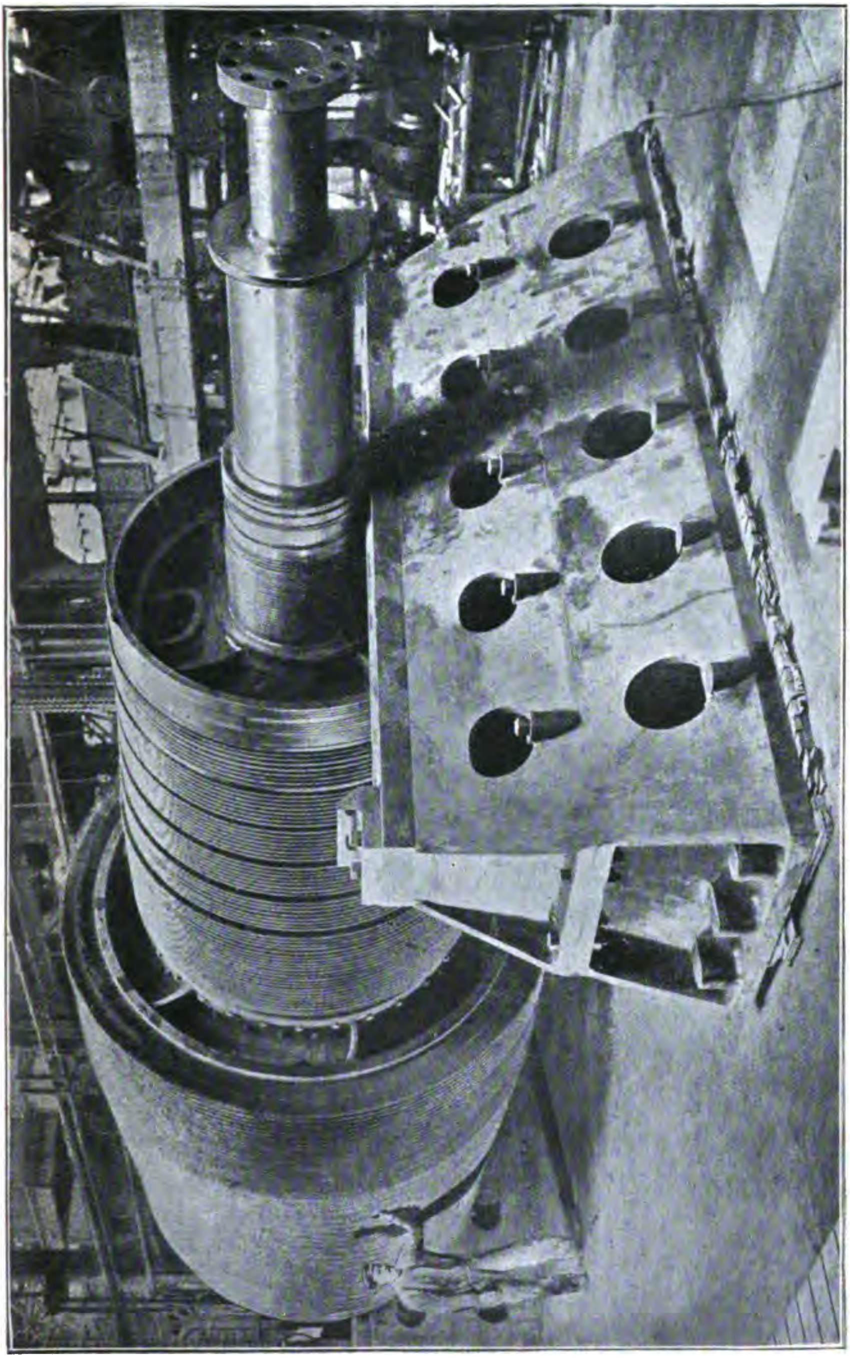


FIG. 496.—"Carmania's" Low-Pressure and Astern Rotor.

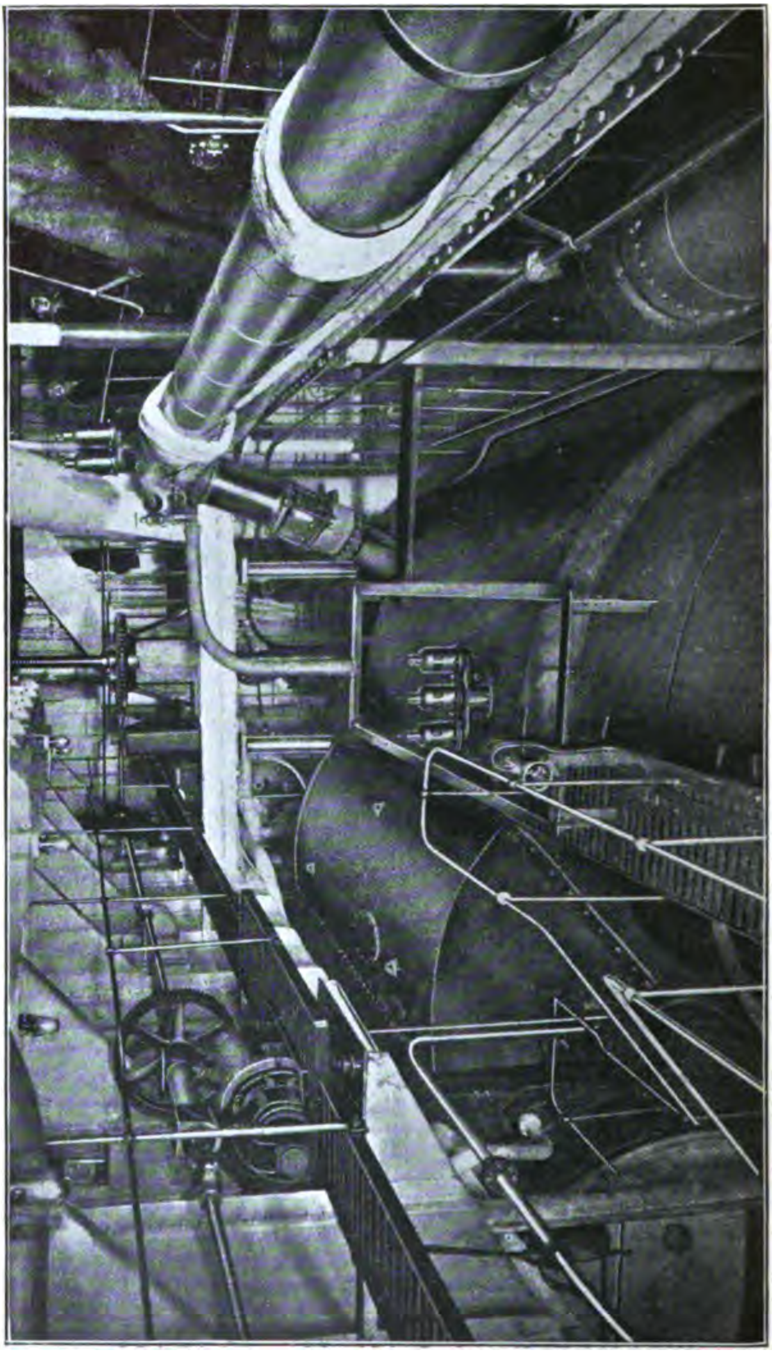
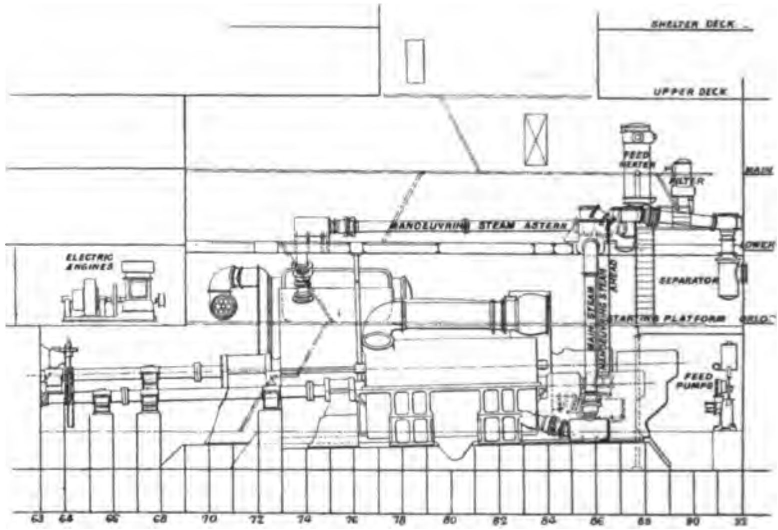


FIG. 497.—"Carmania's" Turbine-Room, looking aft.

FIG. 498.—Propellers of "Carmania," Cunard Line.

FIG. 499.



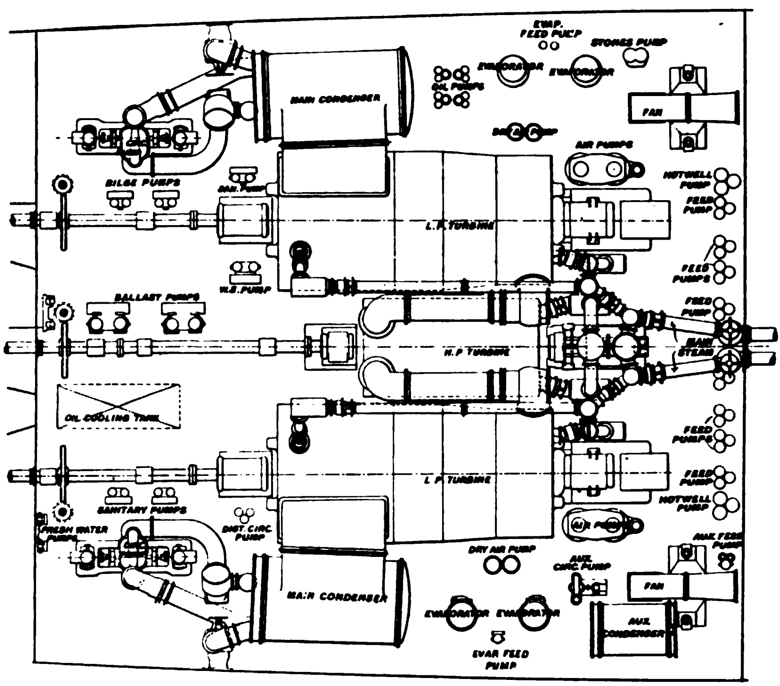
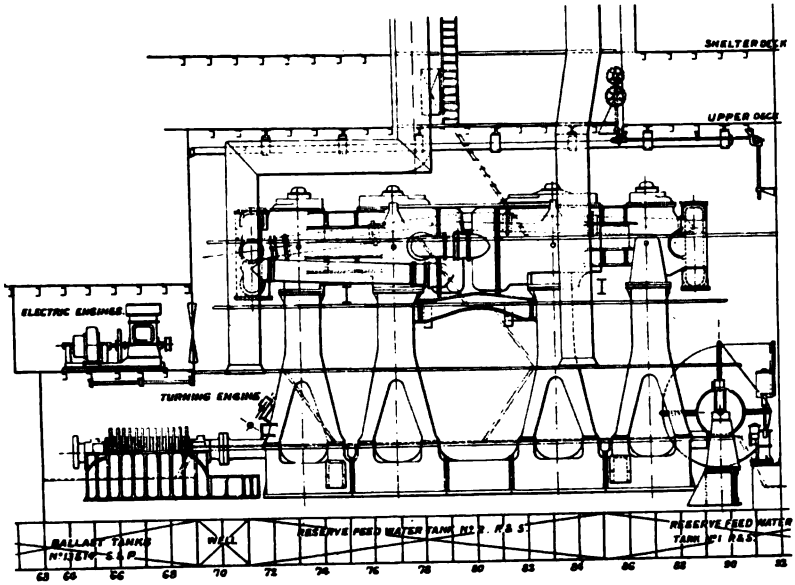


FIG. 500.

FIGS. 499 and 500.—"Carmania's" Turbine-Room: Elevation and Plan.

FIG. 501.



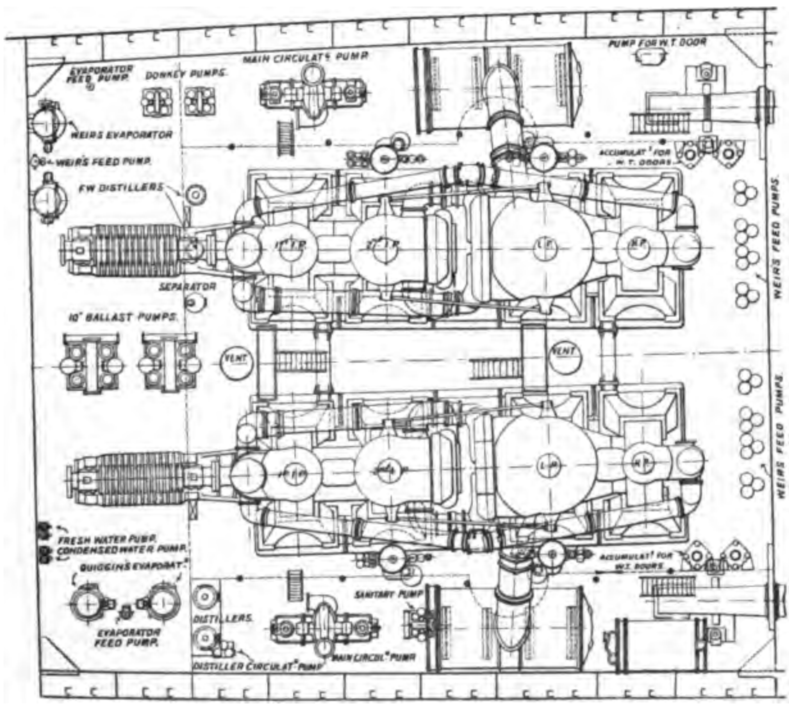


FIG. 502.

FIGS. 501 and 502.—"Caronia's" Engine-Room : Elevation and Plan.

	Turbine Steamers.				*Reciprocating.*	
Name of Vessel	"Carmania."	Unnamed.	..	Ordered July, 1905.	*Caronia.*	*Campania* and *Lucania.*
Hotwell pumps	2	...	...	...	...	...
Made by	Weir	...	...	...	...	...
Diameter	12½in.	...	...	...	...	...
Stroke	24in.	...	...	...	...	...
Oil circulation :—	4 Weir pumps	...	...	...	...	...
Steam consumed p. hour	...	...	...	...	...	...
Weights :—						
Boilers, including water	...	...	...	...	...	...
Turbine machinery	...[1]	..[2]	...	...	...	...
Main reciprocating engines	...	...	...	...	105% of "Carmania's" weight	...
Shafting	...	...	...	...	...	...
Total	...	...	...	...	...	...
Saving of weight over reciprocating engine	...	2% to 3%	same	...	...	...
Costs	...	...	...	...	...	...
Test Results :—						
Number of boilers in use	...	...	...	...	...	...
Guaranteed speed, knots per hour	...	...	...	...	*19*	...
Six-hour trial speed	...	...	...	...	*19·45*	...
Mean speed of four runs on measured mile	20·19	...	...	...	*19·62*	...

[1] Each l.p. turbine weighs 340 tons.
[2] Each l.p. turbine will weigh about 420 tons. "Carmania's" turbines contain 1,115,000 blades.

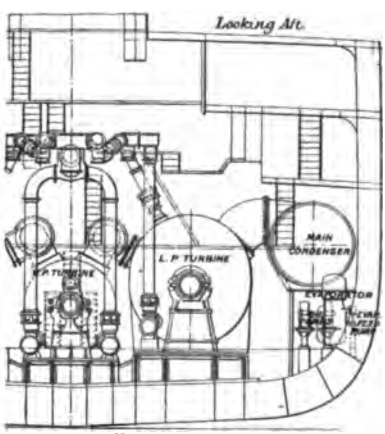


Fig. 503.

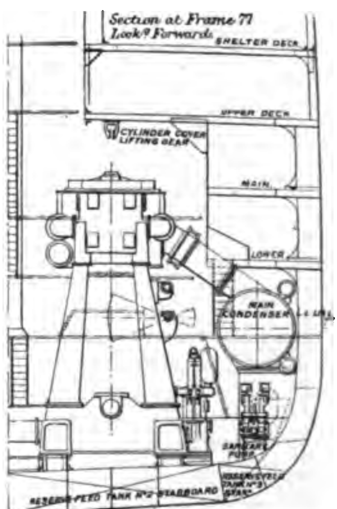


Fig. 504.

Figs. 503 and 504.—Cross-Section "Carmania" and "Caronia" Engine-Rooms.

FIG. 505.—25-Knot Cunard Co.'s Turbine Vessel. ("Susitania" and "Mauritania.")

TABLE CXLIV.—RESULTS OF OFFICIAL TRIAL "CARONIA."

	Mean of 4 Runs.	Average for 12 Hours.
Revolutions per minute	*89·2*	*88·3*
I.H.P. port	*10,986*	*10,440*
I.H.P. starboard	*10,884*	*10,610*
Total I.H.P.	*21,870*	*21,050*
Boiler pressure . . . lbs. per sq. inch	*205*	*205*
H.P. receiver pressure . . "	*194*	*193*
1st I.P. receiver . . . "	*98*	*95*
2nd I.P. receiver . . . "	*48*	*46*
L.P. receiver . . . "	*11·5*	*11*
Air pressure in ashpits	*·7in.*	*·7in.*
Mean speed of ship . . . knots	*19·62*	*19·45*

Type	American Turbine Vessels.					
		Turbine[1] Steamship Co., Toronto.	Private Yacht.	U.S.A. Navy Turbine Vessels.		
Name of Vessel	"**Revolution.**"	"**Turbinia**" (the second)	Designer T. B. Taylor, 221 Mercer Street, New York.	Armoured Cruiser.[2]	**Scout "Salem."**	**Scout "Chester."**
Date of launch	1902	Mar. 30, 1904	...	1905 (?)	...	...
Name of builder	...	Hawthorn, Leslie, & Co., Ltd.	...	...	...	..
Place	...	England	...	...	...	...
Vessel's length overall	178ft.	260ft.	30ft.	...	420ft.	420ft.
Length between perpendicular	140	250	...	...	...	...
Beam	17ft.	33ft.[3]	5ft.	...	46⅚ft.	46⅚ft.
Beam, including rolling chocks	...	...	...	...	...	...
Depth, upper deck to keel	...	...	...	...	...	...
Draught	7ft.	20¾ft.	3ft.	...	16¾ft.	16¾ft.
Displacement	...	1350 tons 1100[4]	...	14,000 tons	3750 tons	3750 tons

[1] To suit canals between St Lawrence river and Hamilton.

[2] A second for this service, but American built, was announced by *The Engineer*, p. 471, Nov. 11th, 1904.

[3] *The Engineer*, Feb. 24th, 1905.

[4] *Marine Engineer*, January 1905.

		Turbine Steamship Co., Toronto.	Private Yacht.	U.S.A. Navy Turbine Vessels.		
Name of Vessel	"Revolution."	"Turbinia" (the second)	Designer T. B. Taylor, 221 Mercer Street, New York	Armoured Cruiser.	Scout "Salem."	Scout "Chester."
Speed forward	...	18·46 knots	...	...	24 knots	24 knots
Speed per hour astern	...	...	...	...	...	...
Length of journey	...	...	...	...	...	...
Average running speed	18	...	...	...	...	...
Horse-power I.H.P.	1800	5000	...	...	16,000	16,000
Boilers:—						
Maker	Seabury	...	...	...	...	...
Type	Double-ended	Single-end	...	...	...	...
Number installed	2	2	...	...	...	...
Length	...	10ft. 6in.	...	...	...	...
Diameter	...	17ft. 6in.	...	...	...	...
Furnaces	...	4 Morison	...	...	...	...
Diameter	...	42in.	...	...	...	...
Heating surface, total	...	6688 sq. ft.	...	...	...	...
Grate area	94 sq. ft.	182 sq. ft.	...	...	...	...
Draught pressure (water)	...[1]	...[2]	...	...	...	...
Steam pressure — lbs. per sq. in.	250[2]	160	...	..	250	250
Heating surface per I.H.P.	...	1·97	...	...	...	...
Heating surface per sq. ft. grate	...	36·7	...	...	...	...
I.H.P. per sq. ft. of grate	...	18·7	..	...	...	...
Superheaters	...	...	...	...	Probably none	none
Shafts:—						
Number	2	3	1[3]	...	4	...
Diameter	...	5½in.	...	...	...	...
Propellers per shaft	1	Bronze	...	...	1	1
Number of blades each	3	...	2	...	...	...
Length of blades	...	...	6ins. long	...	...	...
Diameter	4ft. 6in.	49in.	...	...	...	...
Pitch	3ft. 4in.	44in.	12ins.	...	...	...
Steam Turbine:—						
Made by	...	Parsons Marine Steam Turbine Co.	...	...	Parsons turbine	Curtis turbine

1 Produced by small Curtis turbine, 2800 revolutions per minute.

2 H.P. turbine 122 lbs.; L.P. turbine 45 lbs.; Vacuum 27½ inches.

3 The shaft is inside a 15-inch diameter tube between hull and keel, beginning 5 feet abaft the bow, and ending 5 feet forward of stern, and is geared to turbine. *Engineering Times*, p. 418, September 1st 904. Repeated inquiries by letter bring no news of tests.

		Turbine Steamship Co., Toronto.	Private Yacht.	U.S.A. Navy Turbine Vessels.		
Name of Vessel	"Revolution."	"Turbinia" (the second)	Designer T. B. Taylor, 221 Mercer Street, New York	Armoured Cruiser.	Scout "Salem."	Scout "Chester."
Type	Curtis	Parsons	...	...	...	...
Number	Two independent turbines, two-stage compound reversible	...	...	...	...	...
High-pressure Turbines:—						
Number	...[1]	1	...	...	...	...
Position	...	centre shaft	...	...	...	...
Revolutions per minute	650 max. 250 min.	650	...	...	500	...
Low-pressure Turbines:—						
Number	...	2	...	...	...	...
Position	...	each side	...	...	...	...
Revolutions per minute	...	..	...	...	...	...
Go-astern Turbines:—						
Number	Vanes on outer rims	...	...	...	...	...
Position	In casing of 2nd stage	...	...	...	...	...
Revolutions per minute	...	...	...	...	...	...
Rated horse-power condensing	...	...	...	...	...	...
Rated horse-power non-condensing	...	...	...	...	...	...
		h.p. | l.p.				
Steps of blades	...	7 | 5	...	...	...	...
Each row	...	5 to 7 |	...	...	...	...
Diameter: inches	...	40 | 48	...	...	...	...
,, outside case	...	48 | 56	...	...	...	...
Length—feet	...	8 ft. 6in. | 11ft. 0in.[2]	...	...	...	...
,, of blades	...	$1\frac{1}{4}$ ins. to 6 ins.	...	...	...	...
Clearance	...	0·03 ins.	...	...	...	...
Condenser:—						
Made by	...	...	...	...	...	...
Type	...	...	...	...	...	...

1 Steam enters through four nozzles into 1st stage, where it expands from 265 lbs. per sq. inch absolute to 16 lbs. per sq. inch absolute. It passes through another set of four nozzles into 2nd stage, where it expands to less than 1 lb. per sq. inch.

2 Go-ahead 5 feet 6 ins., go-astern 5 feet 6 ins., total 11 feet 0 ins.

		Turbine Steamship Co., Toronto.	Private Yacht.	U.S.A. Navy Turbine Vessels.		
Name of Vessel . .	"Revolution."	"Turbinia" (the second)	Designer T. B. Taylor, 221 Mercer Street, New York	Armoured Cruiser.	Scout "Salem."	Scout "Chester."
Number . . .	2	...	...	..	...	...
Surface of each . .	1100 sq. ft.	...	...	...	50 per cent. more surface than in sister ship with reciprocating engines.	
Diameter of intake .	20 ins.	..	...	...	...	...
Injection . . .	"Bottom scoop"	...	...	...	...	...
Auxiliary pump . .	steam	...	...	...	...	...
Power used by . .	4 ins. × $4\frac{1}{2}$ ins.	...	...	...	...	...
Air Pumps:—						
Number . . .	2	2	...	...	...	...
Maker. . . .		...	...	...	...	...
Type	Double Blake	...	...	...	...	...
Vacuum maintained at full speed	28 ins.	...	...	...	...	...
Barometric pressure .	not stated	...	...	...	...	...
Temperature of discharge at full speed	...	...	...	...	...	...
Steam per hour used at full speed	...	...	...	...	...	...
Air pump barrel diameter and stroke	6 ins. × 12 ins. × 8 ins.	... ...	... ...	... ..	... ...	... ...
Steam cylinder diameter	...	...	...	...	...	...
Strokes per minute	...	...	...	...	...	...
Circulating Pump:—						
Made by . . .	...	...	...	...	...	...
Driven by engines	...	2, 9ins. × 7ins.	...	...	...	...
Steam per hour at full speed	...	200 r.p.m.	...	...	...	...
Weight of circulating water per unit weight of steam	...	...	...	...	...	...
Temperature suction .	...	...	...	...	...	...
,, discharge.	...	...	..	...	...	...
Electric-lighting Engine:						
Maker . . .	...	...	...	...	...	...
Type	Curtis turbine	...	...	...	...	...
K.W. capacity each .	...	...	...	...	...	...
Position . . .	...	...	...	...	...	...

		Turbine Steamship Co., Toronto.	Private Yacht.	U.S.A. Navy Turbine Vessels.		
Name of Vessel	"Revolution."	"Turbinia" (the second)	Designer T. B. Taylor, 221 Mercer Street, New York	Armoured Cruiser.	Scout "Salem."	Scout "Chester."
Feed Pumps:—						
Made by	...	...	..	...	...	...
Type	Blake	Woodeson	...	...	...	...
Number	2	2	...	...	...	...
Water cylinder diameter	6 ins. × 9 ins. × $3\frac{3}{4}$ ins. × 8 ins.	...	...	...	...	...
Stroke	...	...	...	...	...	...
Steam cylinder diameter	...	28ins.	...	...	...	...
Capacity per hour	...	...	...	...	...	...
Steam consumed per hour	...	...	...	...	...	...
Oil circulation:—	Blake duplex 2 ins. × $1\frac{1}{4}$ in. × $2\frac{3}{4}$ ins.	Two Weir	...	...	...	...
Steam consumed per hour	...	...	...	...	...	...
Pressure	...	5lbs.	...	...	...	...
Weights:—						
Boilers, including water	...	140 tons	...	...	...	...
[1] Turbine machinery throttle to exhaust	$8\frac{3}{4}$ lbs. per I.H.P.	58	...	...	...	...
Shafting	...	5	...	...	...	...
Auxiliary machinery	...	...	...	...	...	...
Costs	...	...	...	...	..	...
Tests	See p. 733	See p. 734	...	...	...	...
Engine-room staff for estimated H.P.		3400 H.P. 1 engineer 1 oiler and water tender 3 firemen 1 coal passer				

[1] Reciprocating engines of torpedo boats $11\frac{1}{4}$ lbs. per I.H.P. The turbines in *Revolution* had never been apart since first put up, covering a period of $1\frac{1}{4}$ years.—Report, U.S. Navy Bureau of Steam Engineering, Oct. 6th, 1903. Trials under control of Professor E. Denton from 96 to 1100 brake horse-power.

Tests of the "Revolution."—Tests have been made to determine the power given out by the turbines. A length of torsion-shaft was inserted in the tail shafting, and apparatus was provided for ascertaining the angle of torsion. At the same time the steam condensed during the tests was pumped into measuring

tanks on deck. The trials were under the control of Professor James E. Denton. Tests were made at various powers, ranging from 96 brake horse-power to 1100 brake horse-power per turbine, and Professor Denton reports:—"The economy from the turbine is therefore probably quite equal at full power to that afforded by average high-speed marine triple-expansion engines, and it is nearly the same for one-tenth of full power." He adds, that by an improvement, which he suggests, the water consumption can be considerably reduced. The weight of each turbine, from its throttle valve to the exhaust pipe flange, is 8¾ lb. per indicated horse-power, and the space occupied is one-tenth of a cubic foot per indicated horse-power. The indicated horse-power is arrived at by adding a percentage to the brake horse-power. The *Revolution* commenced her trials in April 1902, and has been running for many months. No repairs whatever have been made on the turbines, and so far there has been no appreciable wear. Three pairs of screws were designed and built for the boat before the trials commenced. The speed proved to be very nearly the same with all of them, although the revolutions of the turbines varied from 750 to 600 per minute. As the displacement of the vessel is 18 per cent. more than the builders estimated, none of the screws is exactly adapted to the conditions (*Engineering*, December 11th, 1903, p. 806).

1800 I.H.P. was developed at 672 revolutions per minute, using 18·14 lbs. per I.H.P. in these two-stage Curtis turbines. (From Professor Denton's tests, *Jour. Am. S.N.A.*, November 1903.)

Quick Stop Trials.—Running full speed ahead, then suddenly reversing both turbines, the vessel came to a standstill in 32 seconds.

Curtis Turbine *versus* **Reciprocating Engines.**—Reciprocating engines, built especially light for U.S. torpedo boats, weigh 11½ lbs. per I.H.P., as compared with 8¾ lbs. per equivalent I.H.P. of the Curtis turbines in the *Revolution*.

Oil Consumed by Reciprocating Engines.—One gallon of oil per ton of coal burnt was given as a rough figure for the oil consumed in marine reciprocating engines, by *The Steamship*, August 1904, p. 43.

Turbinia (the second).—Passage to America, Stornoway to Sydney, Cape Breton, 6 days. Average speed 17½ knots per hour. Coal capacity 110 tons.

TABLE CXLV.—"TURBINIA" (THE SECOND) TRIALS.

Pressures.	On Lake Ontario.	Regular Runs.	
Boiler—lbs. per sq. in.	160	135	160
In pipes	...	...	140
H.P. Turbine—lbs. per. sq. in.	122	90	115
L.P. " " "	45	32	40
Vacuum, mercury	27½in.	27in.	26½in.
" astern turbine	...	...	28in.
Barometer	...	...	...
Distance, miles (5280 ft.)	31½	31½	...
Time, minutes	80	85/90	...
Coal—lbs. per I.H.P. hour	1·46	...	...
Feed water, temperature F.	178°	...	...
Evaporation—lbs. per lb. coal	8	...	...
R.p.m. centre Turbine	...	550/575	640
R.p.m. starboard wing	...	600	680
Revolutions per minute port wing	...	600	688
Oil pump pressure—lbs.	...	...	7
Temperature injection water	...	...	52° F.
" discharge	...	...	94° F.

Service . . . . Belgian State Railways.
Route . . . . Dover–Ostend.

	Turbine Vessels.	
Name of Vessel	"Indépendance."[1]	"Princess Elizabeth."[2]
Date of launch	...	Mar. 30, 1905
Name of builder	Société A. John Cockerill	
Place	Hoboken, Belgium	
Vessel's length over all	357ft.	355ft.
Length between perpendicular	344ft.	344ft.
Beam	40ft.	40ft.
Beam, including rolling chocks	42½ft.	344
Depth, upper deck to keel	15ft. (?)	30½ft.
Depth, promenade deck to keel	23¼ft.	...
Draught	9¾ft.	9ft. 7in.
Passenger accommodation	...	1000
Speed forward	23 knots	24 knots
Horse-power—'I.H.P.' estimated	12,000	...
Boilers:—		150 lbs. per sq. in.
Type	...	Multitubular
Number	...	8
Steam Turbines:—		
Made by	...	Parsons
Number	...	3
Type	...	...

[1] This was tenth vessel added to fleet of nine reciprocating vessels. The "Princess Clémentine" has reciprocating engines of 9000 I.H.P.

[2] "Princess Elizabeth" has 19,800 sq. ft. heating surface, 484 sq. ft. grate, H.P. turbine in centre and l.p. on each side, 500 R.p.m., 16 knots speed astern. Rudders fore and aft.

FRENCH NAVY: TORPEDO-BOATS.

Name of Vessel	No. 243.	No. 293.	No. 294.
Date of launch	...	Mar. 17, 1904	...
Date of trial	Dec. 1902, Jan. 1903	June 1904	...
Name of builder	Société des Forges et Chantiers de la Méditerranée	Augustin Normand & Cie	...
Place	Havre	Havre	Gironde
Vessel's length overall	...	130ft. (39·5 metres)	...
Length between perpendicular	...	...	...
Beam	...	14ft. (4·25 metres)	...
Beam, including rolling chocks	...	...	...
Depth, upper deck to keel	..	2·65m.	...
Depth, promenade deck to keel	..	...	...
Passenger accommodation:—			
Armament	...	A bow and a deck torpedo tube. Two 37 mm. guns	
Displacement	92 tons	94·6 tons	...
Speed forward, knots	21[2]	26	18
Speed astern, knots	8	...	nearly 18
Length of journey	...	...	...
Average running speed	...	...	..
Horse-power nominal	1800	1950	...
Boilers:—			
Maker	...	Normand	...
Type	...	water tube	...
Number installed	...	2	...
Rated capacity (lbs. per hour)	...	...	...
Heating surface, total	...	252 sq. m.	...
Grate area	...	5·37 sq. m.	..
Draught pressure (water)	...	0·1m.	...
Steam pressure per sq. in.	...	250 lbs. (17·5 Kgs.)	...
Steam pressure per sq. cm.	...	...	...
Funnels:—			
Number	...	2	...
Diameter	...	0·73m.	...
Superheaters:—		none	
Maker	...	...	...
Type	...	...	...
Heating surface, total	...	...	...
Grate area, if separately	...	...	...
Fired	...	...	...
Capacity	...	...	..
Degrees superheat added	...	...	...
Shafts:—			
Number	2	3	3
Diameter	...	...	...
Weight	...	...	...
Angle with horizontal	11°[2]	...	...

[1] Hull designed for reciprocating engines. An ordinary torpedo-boat hull.

[2] It would have been 24 knots per hour with shafts suitably placed. The conditions laid down have created such difficulties that Professor Rateau stated before the Institution of Naval Architects, Mar. 25th, 1904, it had been impossible to get a satisfactory speed.

FRENCH NAVY: TORPEDO BOATS—*continued.*

Name of Vessel	No. 248.	No. 293.	No. 294.
Propellers, per shaft	...	1	...
Propellers, total	3 (1904)	3	2
Number of blades each	6 5[1]	...	6
Diameter	4 3	...	...
Slip	various trials	22·2 per cent.	...
Steam Turbine:—			
Made by	Sautter, Harle & Co., Paris	Parsons M.S.T. Co., Ltd.	Breguet - de Laval
Type	Rateau Multicellular, designed 1899	...	...
Number	2	4, and 2 astern	2
Rudders	...	...	Fore and aft
Cruising Turbine:—			
Number	...	1	...
Position	...	Centre shaft	...
Revolutions per minute	...	...	...
High-pressure Turbine:—			
Number	...	1	1
Position	...	Port shaft	Starboard shaft
Revolutions per minute	...	...	...
Intermediate-pressure Turbine:—			
Number	...	1	1
Position	...	Starboard shaft	Port shaft
Revolutions per minute	1800	...	...
Low-pressure Turbine:—			
Number	...	1	1
Position	...	Centre shaft	Centre shaft
Revolutions per minute	...	...	...
Go-astern Turbines:—			
Number	...	...	...
Position	A single ring inside l.p. end of each main turbine	In aft end of low-pressure turbine	...
Revolutions per minute	...	...	...
Rated horse-power condensing	...	...	...
,, ,, non-condensing	...	...	...
Steam consumed	See p. 737	...	...
Weight of steam per hour full speed	...	...	...
Coal burned per hour full speed	...	2000 Kgs.	...
Condenser:—			
Made by	...	Normand	...
Air pump driven	...	by worm gear from centre shaft	...
Circulating Pump:—			
Photo of vessel	Fig. 506	...	...
Stern, showing propellers	Fig. 507	...	...[2]

1 *The Engineering Times*, June 16th, 1904, p. 152. Torpedo-Boat No. 248 will receive five three-bladed propellers.

2 Fig. 336, p. 212, *Sosnowski* shows three shafts. *The Engineer*, Sept. 16th, 1904, p. 276, says two shafts.

FRENCH NAVY: TORPEDO-BOATS—*continued.*

Name of Vessel	No. 243.	No. 293.	No. 294.
Feed Pumps:—			
Made by	...	Weir	...
Type	...	Main and auxy.	...
Feed heater by	...	Normand	...
Oil circulation:—			
Steam consumed per hour	...	...	...
Filter by	...	Normand	...
Weights:—			
Boilers, including water	..	19·800	...
Turbine machinery	...	...	...
Main reciprocating engines	...	...	...
Shafting	...	...	...
Total	...	...	...
Test Results:—			
Guaranteed speed	20 knots	24 knots	...
Mean speed on measured mile	21	26·66	...
Number of runs averaged	...	3	..
Mean speed 2 hours continuous run	...	26·2	...
Revolutions per minute h.p. turbine	...	...	1120 at 18 knots, unofficial
Revolutions per minute l.p. turbine	...	...	...
Consumption of steam during—			
8 hours' trial at 14 knots per hour	...	764lbs. per hour (347 Kgs.)	...
Condition of vessel	...	Rather foul	...
No. 243 has been tried with six different arrangements of propellers, in pairs and by threes on each shaft:—			
Highest speed at full power	18 to 21 knots	...	...
Corresponding to variation of efficiency of	40 per cent.	...	...
Results of two trials	Tables pp. 740, 741.	...	...

TABLE CXLVI.—TEST RESULTS OF A RATEAU TURBINE DRIVING A THREE-PHASE ALTERNATOR. (DUPLICATE OF TURBINE IN FRENCH TORPEDO-BOAT NO. 243.)

Revolutions per Minute.	Admission Pressure Lbs. per Sq. In.	Steam, Lbs. per Hour	Thermodyn. Efficiency per cent.
400	80	8,000	49
500	92	9,000	51
600	105	10,400	52
700	118	11,600	53
800	132	13,000	54
900	145	14,000	"
1000	157	15,300	"
1100	170	16,700	"
1200	183	17,900	"

FIG. 506.—French Torpedo-Boat "No. 293" on Full-Speed Trials.

Constructed by Augustin Normand & Co., Havre. Turbines by Sautter, Harlé & Co., Paris.

Length 180 Ft., Breadth 14 Ft. Displacement (loaded with 19½ Tons) 94·6 Tons, 1950 Horse-Power, 26·66 Knots.

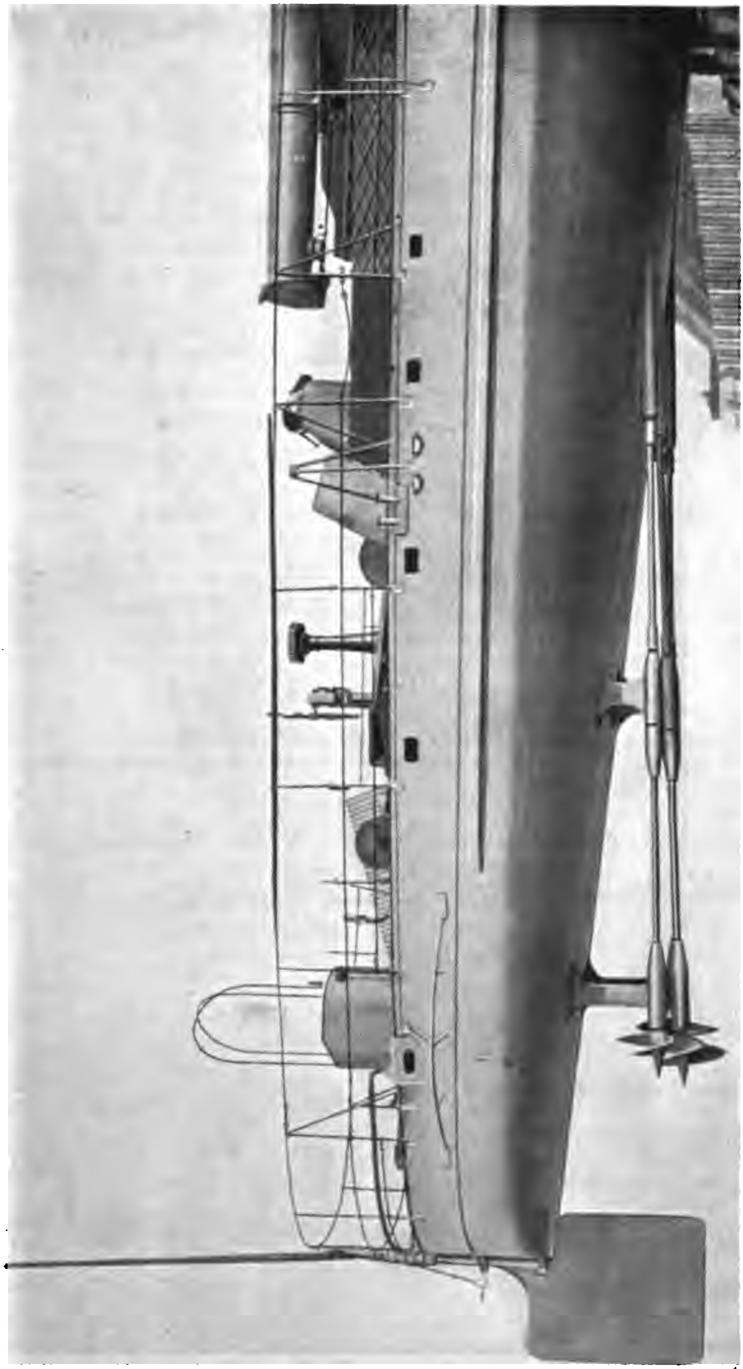


FIG. 507.—Propellers of French Torpedo-Boat "293." (From Turbinia Deutsche Parsons Marine A.G.)

The tests were made under the direction of French Admiralty engineers on a liquid resistance 'load,' the turbine tested being a duplicate of that installed in French Torpedo Boat No. 243.

The efficiencies represent the following ratio:—

$$\text{Efficiency} = \frac{\text{effective power developed on turbine shaft}}{\text{power in steam consumed, assuming no loss between pressure of admission and pressure at exhaust into condenser.}}$$

(See Figs. 236, 237, pp. 358, 359.)

The values tabulated were obtained by reducing the speed of rotation to the uniform speed of 1700 revolutions per minute, and the condenser vacuum to 26 inches of mercury.

The test gave 54 per cent. efficiency. The original estimated value is stated to have been 53 per cent.

At full power—

Steam pressure on admission	145 lbs. per sq. in
Revolutions per minute	900 [1]
Total steam per hour	14,000 lbs.
Steam per effective H.P. hour on shaft	15·2 lbs.[2]
Efficiency as defined above	54 per cent.
Effective H.P. on shaft $\frac{14{,}000}{15\cdot2}$	920 H.P.

[1] Professor Rateau, before Institution of Naval Architects, Mar. 25th, 1904.

[2] At 1800 R.p m., the speed for which the turbine was designed, the efficiency is rather higher and consumption lower.

TABLE CXLVII.—FRENCH TORPEDO-BOAT NO. 243. FITTED WITH RATEAU TURBINES.

Trials run December 6th, 1902.

Four propellers, 20·9 inches diameter, 23·6 inches pitch.

Number of Trial	I.	II.	III.	IV.	V.
Speed- knots—(mean of 2 runs)	14·9	16·59	18·73	18·83	20·89
Revolutions per minute of turbine	1051	1213	1386	1392	1556
Effective pressure on admission to h.p. turbine, lbs. per sq. in.	104·5	80	[1]	99·5	115
Condenser vacuum, inches of mercury	26·4	26·4	26	26·4	26·8
Mean slip of propellers	27·9%	31·1%	30·4%	31·1%	31·6%

[1] Gauges failed. Pressure therefore not recorded.

TABLE CXLVIII.—FRENCH TORPEDO-BOAT NO. 243.

Trials run January 22nd, 1903.

Six propellers: diameter, 23·6 in.; pitch, 19·7 in.

Number of Trial	I.	II.	III.	IV.
Speed of vessel (in knots)—mean of three runs	17·07	19·59	20·94	21·26
Rotation of turbines—revolutions per minute	1348	1572	1748	1774
Effective pressure of steam on admission to turbines—lbs. per sq. in.	68·26	100·98	129·42	132·26
Condenser vacuum—ins. of mercury	28	28	27	27·5
Mean slip of propellers	21·7%	23%	26%	26%

TABLE CXLIX.—FRENCH TORPEDO-BOAT NO. 293.

Trials run June 1904.

Speed—Knots.	Draught.	Per Horse-power Hour. Fuel.	Per Horse-power Hour. Steam.
14	Natural	[1] Same as at 26 knots	Same as at 21 knots
19	...	Less than at 14 knots	Less than at 14 knots
20	...	More than at 19 knots	More than at 19 knots
21	...	The 'cruising' turbine runs idle above this speed	
above 21	...	Less than at 20 knots	...
26 [2]	3·9 ins. (100 mm.) water gauge	Same as at 14 knots	Same as at 19 knots

[1] Eight hours' trial at 14 knots, 351 kgs. of coal per hour.
[2] Two hours' full speed trial, 26·205 knots average.
" " " 26·633 knots maximum.

	German Turbine Cruisers.		Turbine Torpedo-Boat.	German Merchant Marine.	Hamburg-American.
Name of Vessel	"Lübeck."	"Wacht."	S 125.	One.	"Kaiser."
Date of launch	Mar. 26, 1904	...	1904	1904	Apr. 8, 1905
Name of builder	Stettiner Maschinenban A.-G. "Vulcan"	...	F. Schichau	Howaldt's	"Vulcan"
Place	Stettin-Bredow	..	Elbing	Kiel	Stettin
Trials began	May 1905	..	Sept. 1904	...	Aug. 1905
Vessel's length	103·8 metres, *340ft.*	...	63·3 metres, *208ft.*	...	96 metres, *315ft.*
Vessel's length between perpendiculars					92 metres, (*302ft.*)
Beam	13·2 metres, 43ft.	...	7 metres, *23ft.*	...	11·65 metres, *38·3ft.*
Depth	7·75 metres, 25·4ft.	...	...	...	7·20 metres, 23·5ft.
Draught	5 metres, 16·4ft.	..	1·8 metres, 5·9ft.	...	3·03 metres, 10ft.
Displacement	3250 tons	..	413 tons	500 tons	1950 tons
Gross tonnage	...	..	...	...	...
Speed forward	23·88 knots	...	28·92 knots	...	20·46
,, astern	...	..	16·8	...	...
Length of journey	...	...	...	...	...
Average running speed	...	...	...	...	...
Horse-power I. H. P.	10,000/ 12,000	...	7000	..	.
Boilers	...	..	...		4
Maker	Vulcan	...	Schichau		Vulcan
Type	Water-tube	.	Water-tube	...	Water-tube
Number installed	10	..	3	..	...
Rated capacity (lbs. per hour)	...	...	.	.	...
Heating surface, total	...	...	...	...	...
Grate area	...			..	...
Draught pressure (water)		.	..	...	Howden's
Steam pressure	...		.	..	14 kgs. per sq. cm. *200 lbs. per sq. in.*
Funnels:					
Number	3		2	...	...
Diameter	...		...	...	...
Superheaters	none	...	none	...	...
Shafts :—					
Number	4	...	3	...	2
Diameters	195 and 162	...	...	...	...
Propellers, per shaft	Experimental 1 and 2	...	one	...	1 each shaft
Number of blades each	3	..	3		
Diameter	...	...	...	...	...

The *Hamburg* is sister ship to the *Lübeck*, but has reciprocating engines.

	German Turbine Cruisers.		Turbine Torpedo-Boat.	German Merchant Marine.	
					Hamburg-American.
Name of Vessel	"Lübeck."	"Wacht."	S 125.	One.	"Kaiser."
Steam Turbine :—					
Made by	*Turbinia*, Deutsche Parsons Marine A.G.	...	*Turbinia*, Deutsche Parsons Marine A.G.	Escher, Wyss & Co. Zürich	A.E.G. Berlin ... ...
Type	Brown-Boveri-Parsons		Brown-Boveri-Parsons	Zoelly	Curtis ...
Cruising Turbines :—					
Number	One h.p., one l.p.	...	One h.p., one l.p.	...	None[1]
Position	Coupled with l.p. shafts	...	Coupled with outer shafts		
High-pressure turbines :—					
Number	2	...	...	...	2
Position	Inner shafts	...	Inner shafts	...	...
Revolutions per minute	..	...	...	...	...
Low-pressure Turbines :—					
Number	2	...	2	...	2
Position	Outer shafts	...	Outer shafts	...	...
Revolutions per minute	...	...	...	...	600
Go-astern Turbines :—					
Number	4	...	..	2	2
Position	2 coupled with h.p. turbines and 2 in back casing of l.p. turbines	..	... 2 in back casing of l.p. turbines	... ...	enclosed in l.p. turbine ...
Rated horse-power condensing	11,000	...	...	...	6000
Rated horse-power non-condensing	...	...	...	...	..
Steam consumed	...	...	...	...	...
Weight of steam per hour full speed	...	..	...	...	..
Coal burned per hour full speed	...	..	...	...	4060 kgs. per hour at 20 knots
Condenser :—					
Made by	Vulcan	...	Schichau	...	...
Type	Surface	...	Surface	...	...
Number	Two of	..	Two of 280	...	...
Surface	500 sq. m.	...	...	...	...
Air Pump :—					
Maker	2 Weir	...	Weir	...	...

[1] "Kaiser" total weight of turbines 114 tons.

FIG. 508.

FIGS. 508 to 510.—German Cruiser "Lübeck." Stern View
Length 340 Ft., Breadth 43 Ft., Draught 16 Ft. 5 Ins. Displacement 3250 Tons.
Trials commenced March 1905. (*Photos supplied*

Fig. 509.

Fig. 510.

and Two Views of Port Propellers.

Speed guaranteed 22 Knots, 8 Experimental Propellers. Launched 1904.

by Messrs Turbinia D. Parsons Marine A.G.)

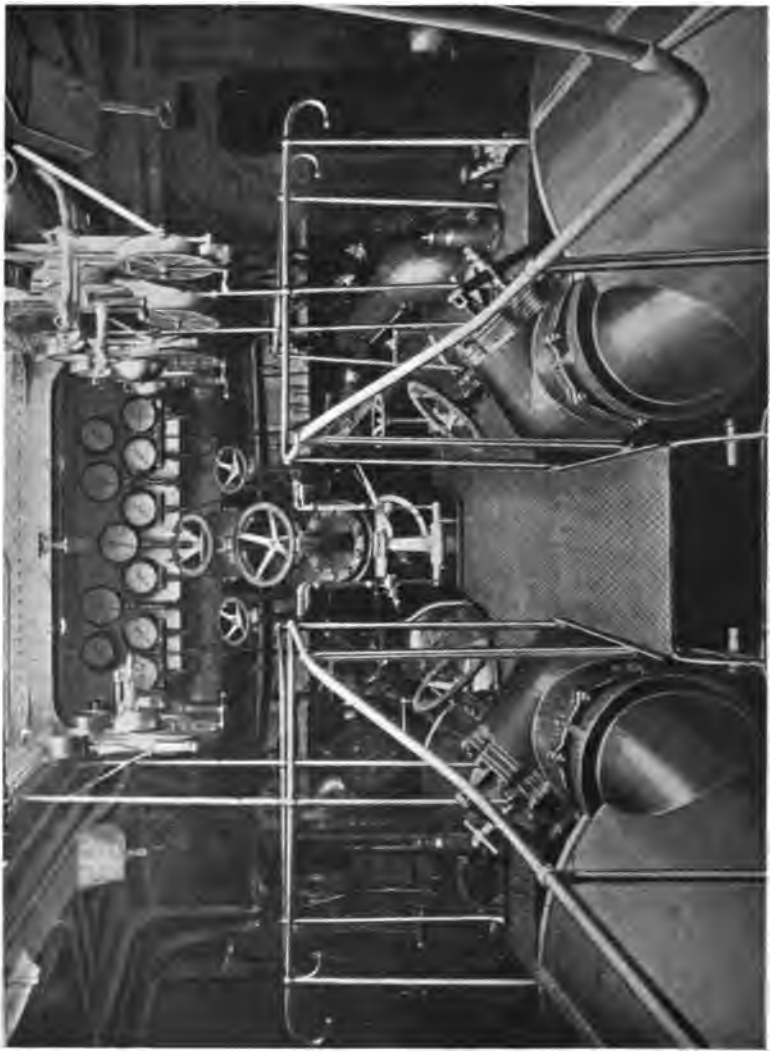


FIG. 511.—German Deep-Sea Torpedo-Boat "S 125." View of Turbine-Room.

FIG. 512.

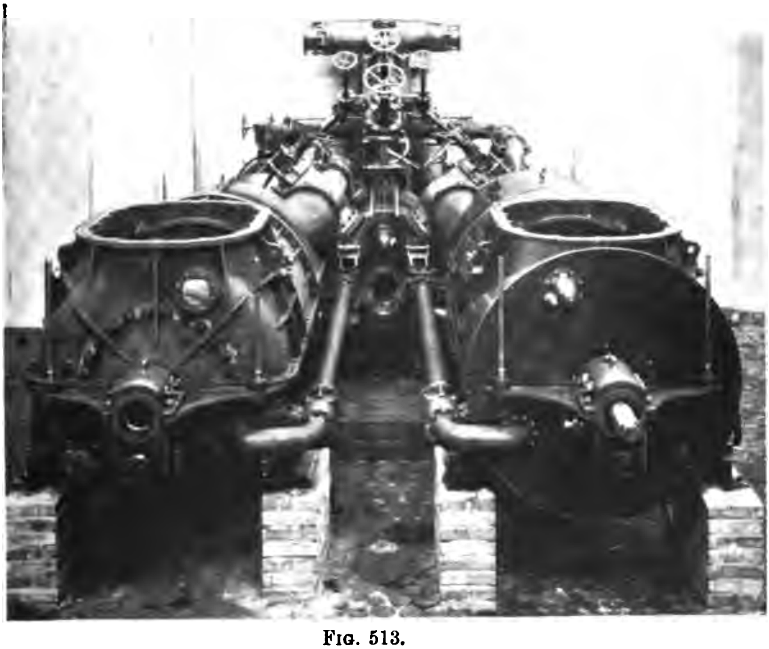


FIG. 513.

FIGS. 512 and 513.—Two Views of Turbines of German Torpedo-Boat "S 125,"—3 Shafts.

(*Photos supplied by Turbinia Deutsche Parsons Marine A.G., Berlin.*)

	German Turbine Cruisers.		Turbine Torpedo-Boat.	German Merchant Marine.	
					Hamburg-American.
Name of Vessel . .	"Lübeck."	"Wacht."	S 125.	One.	"Kaiser."
Type	...	...	Independent dry air pump	...	...
Vacuum maintained at full speed	...	...	.		
Temperature of discharge at full speed	...	...	...		
Steam per hour used at full speed	. .	...		...	
Air pump barrel diameter and stroke	..	...	...	...	...
Steam cylinder diameter	..	...	. .		
Strokes per minute .	...	...	.	...	...
Circulating Pump:—					
Made by . .	Vulcan	...		...	...
Type	Two ordinary	. .	...	...	...
Steam per hour at full speed	...	...	...	...	...
Weight of circulating water per unit weight of steam	...	...	...	..	...
Temperature suction .	...	.	...	...	...
Temperature discharge	...	...	...	...	...
Electric-lighting Engine .	Two	...	...	...	...
Maker . . .	Brown-Boveri	...	...	. .	...
Type	Parsons[1]	...	...	...	..
K.W. capacity each .	45 K.W.	...	...	...	...
Position . . .	...	...	...	...	...
Illustrations . .	pp. 744, 745	...	pp. 746, 747	...	p. 777

[1] The German navy has ordered 30 Parsons turbines for dynamos.

TABLE CL.—RECORD COAL CONSUMPTION—([1] RECIPROCATING ENGINES).

Service.	Vessel's Name.	Per I.H.P. Hour.
French cruiser	*Dupetit Thouars*	1·21 lbs.
Russian cruiser	*Bayan*	1·4 ,,
British cruiser	*Vengeance*	1·5 ,,
British cruiser	*Drake*	1·55 ,,

[1] *The Engineer*, December 23rd, 1904, p. 625.

The Hamburg Heligoland S.S. Co. has a turbine vessel 2000 tons, 300 ft. long, 38 ft. beam, 20 knots, with 2 shafts driven by Curtis turbines built by "Vulcan," Stettin.

CHAPTER XXIV

BIBLIOGRAPHY [1]

WHILE no claim to completeness is put forward for this Bibliography, it is nevertheless, exclusive of library compilations, probably as exhaustive as any which is yet available to the general reader. It comprises not only the books and articles to which the writers have had occasion to refer in the course of their own studies of the subject of "Steam Turbine Engineering," but also a large number of references published from time to time in technical periodicals.

The Bibliography is divided into five sections, dealing respectively with the following subjects:—

The references in each section are arranged in the order of their dates.

SECTION A.

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[1] For the preparation of this Bibliography the authors are indebted to Mr F. R. Senior.

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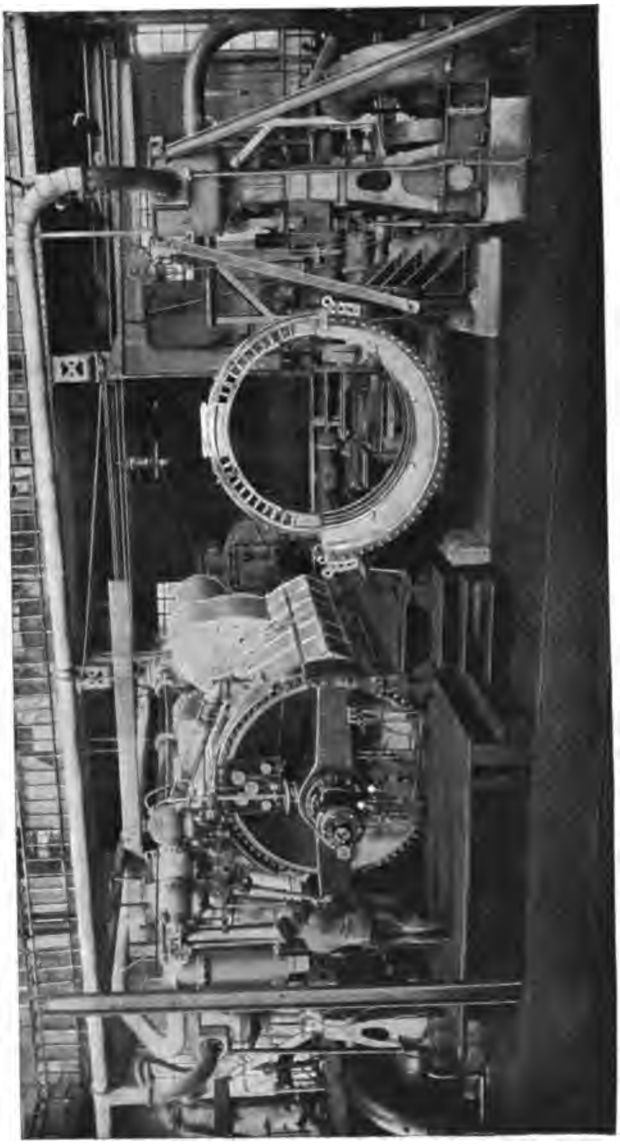

FIG. 514.—3000 H.P. Turbines for "Kaiser" on the test bed.

(*Photo supplied by A.E.G.*)

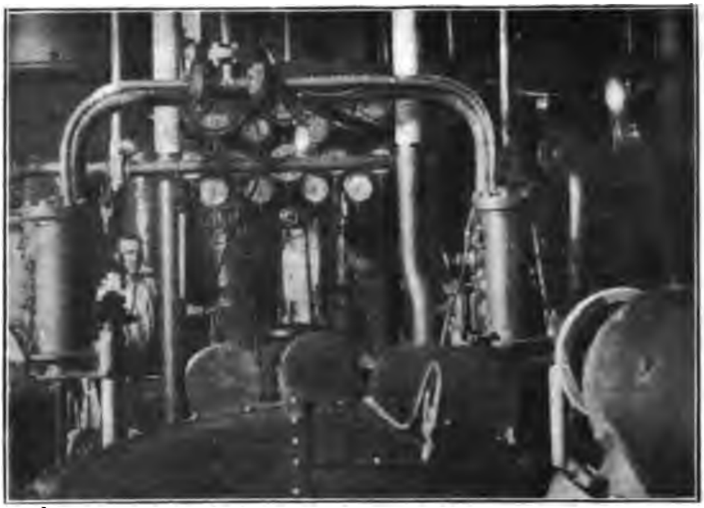

FIG. 515.—" Victorian " Starting Gear. (Taken from top of h.p. turbine.)

FIG. 516.—" Victorian " New Propellers. (Mar. 20, 1906.)
Diameter, 7 ft. 6 in. ; pitch, 7·44 ft.

(*Photos by Chief Engineer J. W. Hendry.*)

APPENDIX

EQUIVALENT CONSUMPTIONS PER KILOWATT HOUR, PER ELECTRICAL HORSE-POWER HOUR, AND PER INDICATED HORSE-POWER HOUR.[1]

Output from Electric Generator corresponding to Engine Consumptions (of Stated Efficiencies) per I.H.P.H. stated in the Columns on the right of this.				Consumption per Indicated Horse-Power Hour. Combined Efficiency of Engine and Generator.									
Consumption per K.W.H. Output.		Consumption per E.H.P.H.		70 per cent.		75 per cent.		80 per cent.		85 per cent.		90 per cent.	
Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*
2·27	5	1·692	*3·73*	1·184	*2·61*	1·270	*2·80*	1·351	*2·98*	1·437	*3·17*	1·523	*3·36*
2·28	*5·02*	1·702	*3·75*	1·190	*2·62*	1·275	*2·81*	1·361	3	1·447	*3·19*	1·532	*3·37*
2·40	*5·29*	1·790	*3·94*	1·252	*2·76*	1·340	*2·95*	1·430	*3·15*	1·520	*3·35*	1·610	*3·55*
2·43	*5·36*	1·815	4	1·270	*2·80*	1·362	*3·00*	1·450	*3·20*	1·543	*3·40*	1·633	*3·60*
2·50	*5·51*	1·864	*4·11*	1·320	*2·87*	1·400	*3·08*	1·493	*3·29*	1·587	*3·50*	1·677	*3·70*
2·60	*5·74*	1·945	*4·29*	1·360	3	1·457	*3·21*	1·554	*3·43*	1·654	*3·64*	1·740	*3·86*
2·68	*5·91*	2	*4·41*	1·400	*3·08*	1·500	*3·31*	1·600	*3·53*	1·700	*3·75*	1·800	*3·97*
2·70	*5·96*	2·01	*4·44*	1·410	*3·11*	1·510	*3·33*	1·613	*3·56*	1·718	*3·78*	1·814	4
2·72	6	2·03	*4·48*	1·420	*3·13*	1·525	*3·36*	1·623	*3·58*	1·724	*3·80*	1·827	*4·03*
2·80	*6·17*	2·09	*4·51*	1·460	*3·22*	1·567	*3·45*	1·670	*3·68*	1·775	*3·92*	1·870	*4·12*
2·82	*6·22*	2·14	*4·71*	1·490	*3·29*	1·609	*3·53*	1·705	*3·76*	1·815	4	1·920	*4·24*
3	*6·61*	2·24	*4·93*	1·565	*3·45*	1·677	*3·70*	1·790	*3·95*	1·900	*4·19*	2·18	*4·44*
3·04	*6·70*	2·27	5	1·590	*3·50*	1·700	*3·75*	1·814	4	1·928	*4·25*	2·04	*4·50*
3·15	*6·95*	2·35	*5·18*	1·645	*3·63*	1·762	*3·89*	1·880	*4·15*	2	*4·41*	2·12	*4·67*
3·18	7	2·37	*5·22*	1·655	*3·65*	1·778	*3·92*	1·892	*4·17*	2·01	*4·44*	2·13	*4·70*
3·20	*7·05*	2·39	*5·27*	1·672	*3·69*	1·792	*3·95*	1·912	*4·22*	2·03	*4·48*	2·15	*4·74*
3·24	*7·14*	2·42	*5·33*	1·695	*3·73*	1·813	4	1·934	*4·27*	2·06	*4·53*	2·18	*4·80*
3·35	*7·38*	2·50	*5·51*	1·750	*3·86*	1·875	*4·14*	2	*4·41*	2·13	*4·70*	2·25	*4·96*
3·38	*7·45*	2·52	*5·56*	1·765	*3·89*	1·890	*4·17*	2·01	*4·44*	2·14	*4·72*	2·27	5
3·45	*7·60*	2·57	*5·67*	1·800	*3·97*	1·930	*4·26*	2·06	*4·54*	2·18	*4·81*	2·31	*5·10*
3·48	*7·66*	2·59	*5·71*	1·816	4	1·950	*4·29*	2·07	*4·57*	2·21	*4·86*	2·33	*5·14*
3·57	*7·87*	2·67	*5·88*	1·867	*4·12*	2	*4·41*	2·13	*4·70*	2·27	*4·91*	2·40	*5·29*
3·58	*7·88*	2·67	*5·88*	1·870	*4·12*	2	*4·41*	2·13	*4·71*	2·27	5	2·41	*5·29*
3·60	*7·93*	2·68	*5·92*	1·880	*4·14*	2·01	*4·44*	2·15	*4·74*	2·28	*5·03*	2·42	*5·34*
3·63	8	2·71	*5·97*	1·897	*4·18*	2·03	*4·48*	2·16	*4·77*	2·30	*5·07*	2·43	*5·37*
3·65	*8·04*	2·72	6	1·905	*4·20*	2·04	*4·50*	2·18	*4·80*	2·31	*5·10*	2·45	*5·40*
3·76	*8·28*	2·80	*6·17*	1·960	*4·32*	2·10	*4·63*	2·24	*4·94*	2·38	*5·25*	2·52	*5·56*
3·81	*8·38*	2·83	*6·25*	1·980	*4·37*	2·13	*4·69*	2·27	5	2·41	*5·31*	2·56	*5·63*

[1] *Power*, March 1904, published the above list in English units only.

Equivalent Consumptions, etc.—*continued.*

Output from Electric Generator corresponding to Engine Consumptions (of Stated Efficiencies) per I.H.P.H. stated in the Columns on the right of this.				Consumption per Indicated Horse-Power Hour. Combined Efficiency of Engine and Generator.									
Consumption per K.W.H. Output.		Consumption per E.H.P.H.		70 per cent.		75 per cent.		80 per cent.		85 per cent.		90 per cent.	
Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*
4	*8·82*	2·93	*6·56*	2·09	*4·60*	2·24	*4·94*	2·38	*5·24*	2·53	*5·57*	2·68	*5·91*
4·05	*8·94*	3·03	*6·67*	2·12	*4·67*	2·27	5	2·42	*5·33*	2·57	*5·67*	2·72	6
4·08	9	3·04	*6·71*	2·13	*4·70*	2·28	*5·03*	2·44	*5·37*	2·59	*5·71*	2·74	*6·04*
4·17	*9·20*	3·11	*6·85*	2·18	*4·81*	2·33	*5·14*	2·19	*5·49*	2·64	*5·82*	2·80	*6·17*
4·26	*9·38*	3·18	7	2·22	*4·90*	2·38	*5·25*	2·54	*5·60*	2·70	*5·95*	2·86	*6·30*
4·30	*9·46*	3·20	*7·06*	2·24	*4·94*	2·40	*5·29*	2·56	*5·65*	2·72	6	2·88	*6·35*
4·34	*9·57*	3·24	*7·14*	2·27	5	2·43	*5·36*	2·59	*5·71*	2·75	*6·07*	2·92	*6·43*
4·40	*9·70*	3·28	*7·23*	2·29	*5·05*	2·46	*5·42*	2·62	*5·77*	2·78	*6·13*	2·95	*6·50*
4·54	10	3·38	*7·46*	2·37	*5·22*	2·54	*5·59*	2·71	*5·97*	2·87	*6·34*	3·04	*6·71*
4·57	*10·05*	3·40	*7·50*	2·38	*5·25*	2·55	*5·62*	2·72	6	2·89	*6·37*	3·06	*6·75*
4·60	*10·13*	3·43	*7·56*	2·40	*5·29*	2·57	*5·66*	2·74	*6·04*	2·91	*6·42*	3·09	*6·81*
4·73	*10·43*	3·53	*7·78*	2·47	*5·44*	2·65	*5·83*	2·75	*6·07*	2·93	*6·46*	3·18	7
4·80	*10·58*	3·58	*7·89*	2·51	*5·54*	2·69	*5·93*	2·86	*6·31*	3·04	*6·70*	3·22	*7·10*
4·87	*10·72*	3·63	8	2·54	*5·60*	2·72	6	2·90	*6·40*	3·08	*6·80*	3·26	*7·20*
4·97	11	3·72	*8·21*	2·61	*5·74*	2·79	*6·15*	2·98	*6·56*	3·16	*6·97*	3·35	*7·38*
5	*11·02*	3·73	*8·22*	2·61	*5·76*	2·80	*6·16*	2·98	*6·57*	3·17	*6·98*	3·36	*7·40*
5·01	*11·04*	3·74	*8·23*	2·62	*5·76*	2·81	*6·18*	2·99	*6·59*	3·18	7	3·36	*7·41*
5·20	*11·46*	3·88	*8·55*	2·71	*5·97*	2·91	*6·42*	3·10	*6·84*	3·30	*7·27*	3·49	*7·69*
5·21	*11·49*	3·89	*8·57*	2·72	6	2·92	*6·43*	3·11	*6·86*	3·31	*7·29*	3·50	*7·71*
5·32	*11·73*	3·97	*8·75*	2·78	*6·12*	2·98	*6·56*	3·18	7	3·38	*7·44*	3·57	*7·87*
5·37	*11·82*	4	*8·82*	2·80	*6·17*	3	*6·61*	3·20	*7·05*	3·40	*7·49*	3·60	*7·93*
5·41	*11·91*	4·03	*8·89*	2·82	*6·22*	3·02	*6·67*	3·23	*7·11*	3·43	*7·56*	3·63	8
5·44	12	4·06	*8·95*	2·84	6·26	3·04	*6·71*	3·25	*7·16*	3·45	*7·61*	3·66	*8·06*
5·47	*12·06*	4·08	9	2·86	*6·30*	3·06	*6·75*	3·27	*7·20*	3·47	*7·65*	3·68	*8·10*
5·60	*12·34*	4·17	*9·20*	2·92	*6·44*	3·13	*6·91*	3·34	*7·36*	3·55	*7·83*	3·76	*8·29*
5·68	*12·51*	4·23	*9·33*	2·96	*6·53*	3·18	7	3·39	*7·47*	3·60	*7·93*	3·81	*8·40*
5·72	*12·62*	4·27	*9·40*	2·98	*6·57*	3·20	*7·05*	3·41	*7·51*	3·63	*8·00*	3·84	*8·46*
5·72	*12·62*	4·27	*9·41*	2·99	*6·59*	3·21	*7·06*	3·42	*7·53*	3·63	8	3·84	*8·47*
5·85	*12·88*	4·36	*9·61*	3·05	*6·72*	3·27	*7·21*	3·49	*7·71*	3·71	*8·18*	3·92	*8·64*
5·90	13	4·40	*9·70*	3·08	*6·79*	3·30	*7·27*	3·52	*7·76*	3·74	*8·24*	3·96	*8·73*
6	*13·23*	4·48	*9·88*	3·13	*6·90*	3·36	*7·40*	3·58	*7·89*	3·80	*8·38*	4·03	*8·90*
6·08	*13·40*	4·54	10	3·17	7	3·41	*7·50*	3·63	8	3·86	*8·50*	4·08	9

EQUIVALENT CONSUMPTIONS, ETC.—*continued.*

Output from Electric Generator corresponding to Engine Consumptions (of Stated Efficiencies) per I.H.P.H. stated in the Columns on the right of this.				Consumption per Indicated Horse-Power Hour. Combined Efficiency of Engine and Generator.									
Consumption per K.W.H. Output.		Consumption per E.H.P.H.		70 per cent.		75 per cent.		80 per cent.		85 per cent.		90 per cent.	
Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*
6·13	*13·50*	4·57	*10·07*	3·20	*7·05*	3·43	*7·55*	3·66	*8·06*	3·89	*8·58*	4·12	*9·08*
6·35	**14**	4·74	*10·44*	3·32	*7·31*	3·50	*7·83*	3·79	*8·35*	4·03	*8·88*	4·26	*9·40*
6·40	*14·11*	4·77	*10·50*	3·34	*7·36*	3·58	*7·90*	3·82	*8·43*	4·05	*8·93*	4·29	*9·47*
6·44	*14·19*	4·81	*10·59*	3·36	*7·41*	3·60	*7·94*	3·84	*8·47*	4·08	**9**	4·32	*9·53*
6·48	*14·30*	4·84	*10·67*	3·38	*7·47*	3·63	**8**	3·87	*8·53*	4·12	*9·07*	4·35	*9·60*
6·60	*14·55*	4·92	*10·83*	3·44	*7·58*	3·69	*8·13*	3·94	*8·68*	4·18	*9·22*	4·43	*9·78*
6·69	*14·74*	4·97	**11**	3·49	*7·70*	3·75	*8·25*	3·97	*8·80*	4·24	*9·35*	4·49	*9·90*
6·70	*14·77*	5	*11·02*	3·50	*7·72*	3·76	*8·26*	4	*8·82*	4·25	*9·36*	4·50	*9·92*
6·76	*14·89*	5·04	*11·11*	3·53	*7·78*	3·78	*8·33*	4·03	*8·89*	4·27	*9·44*	4·54	**10**
6·81	**15**	5·08	*11·19*	3·55	*7·83*	3·81	*8·39*	4·06	*8·95*	4·32	*9·51*	4·56	*10·01*
6·85	*15·08*	5·11	*11·25*	3·57	*7·87*	3·83	*8·44*	4·08	**9**	4·34	*9·56*	4·59	*10·12*
6·90	*15·20*	5·15	*11·34*	3·60	*7·93*	3·86	*8·51*	4·12	*9·07*	4·38	*9·66*	4·63	*10·20*
6·95	*15·32*	5·18	*11·43*	3·63	**8**	3·89	*8·57*	4·14	*9·14*	4·41	*9·71*	4·66	*10·29*
7	*15·43*	5·22	*11·50*	3·68	*8·12*	3·92	*8·64*	4·18	*9·22*	4·44	*9·78*	4·70	*10·35*
7·16	*15·77*	5·34	*11·76*	3·74	*8·23*	4·01	*8·82*	4·27	*9·41*	4·54	**10**	4·80	*10·59*
7·26	**16**	5·42	*11·94*	3·79	*8·35*	4·06	*8·95*	4·33	*9·55*	4·60	*10·15*	4·87	*10·74*
7·30	*16·09*	5·45	**12**	3·81	*8·40*	4·08	**9**	4·36	*9·60*	4·63	*10·20*	4·91	*10·80*
7·37	*16·23*	5·50	*12·12*	3·85	*8·50*	4·13	*9·12*	4·40	*9·70*	4·68	*10·30*	4·95	*10·90*
7·44	*16·38*	5·55	*12·22*	3·88	*8·56*	4·16	*9·17*	4·43	*9·78*	4·71	*10·39*	4·98	**11**
7·50	*16·53*	5·59	*12·31*	3·92	*8·63*	4·19	*9·24*	4·47	*9·85*	4·75	*10·46*	5·03	*11·10*
7·60	*16·76*	5·67	*12·50*	3·97	*8·75*	4·25	*9·37*	4·54	**10**	4·82	*10·62*	5·10	*11·25*
7·67	*16·90*	5·72	*12·60*	4	*8·81*	4·28	*9·45*	4·57	*10·06*	4·86	*10·71*	5·15	*11·35*
7·72	**17**	5·75	*12·68*	4·03	*8·88*	4·32	*9·51*	4·60	*10·15*	4·89	*10·78*	5·20	*11·41*
7·82	*17·23*	5·84	*12·86*	4·08	**9**	4·37	*9·64*	4·67	*10·29*	4·96	*10·93*	5·25	*11·57*
7·87	*17·35*	5·87	*12·94*	4·11	*9·06*	4·40	*9·71*	4·70	*10·35*	4·99	**11**	5·28	*11·65*
7·90	*17·40*	5·88	*12·99*	4·12	*9·07*	4·41	*9·72*	4·71	*10·38*	5	*11·02*	5·29	*11·66*
7·91	*17·43*	5·90	**13**	4·13	*9·10*	4·42	*9·75*	4·72	*10·40*	5·01	*11·05*	5·31	*11·70*
8	*17·64*	5·97	*13·13*	4·17	*9·19*	4·47	*9·85*	4·77	*10·53*	5·07	*11·16*	5·37	*11·83*
8·12	*17·87*	6·05	*13·33*	4·23	*9·33*	4·54	**10**	4·84	*10·67*	5·14	*11·33*	5·44	**12**
8·16	**18**	6·10	*13·43*	4·26	*9·40*	4·57	*10·07*	4·86	*10·74*	5·17	*11·41*	5·48	*12·08*
8·20	*18·07*	6·12	*13·47*	4·28	*9·45*	4·59	*10·11*	4·89	*10·80*	5·20	*11·46*	5·51	*12·13*
8·37	*18·43*	6·24	*13·75*	4·37	*9·62*	4·68	*10·31*	4·99	**11**	5·31	*11·69*	5·62	*12·37*

EQUIVALENT CONSUMPTIONS, ETC.—*continued.*

Output from Electric Generator corresponding to Engine Consumptions (of Stated Efficiencies) per I.H.P.H. stated in the Columns on the right of this.				Consumption per Indicated Horse-Power Hour. Combined Efficiency of Engine and Generator.									
Consumption per K.W.H. Output.		Consumption per E.H.P.H.		70 per cent.		75 per cent.		80 per cent.		85 per cent.		90 per cent.	
Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*
8·50	*18·73*	6·34	*13·95*	4·44	*9·78*	4·75	*10·45*	5·07	*11·17*	5·39	*11·88*	5·70	*12·55*
8·51	*18·77*	6·35	14	4·45	*9·80*	4·76	*10·50*	5·08	*11·2*	5·40	*11·90*	5·71	*12·60*
8·59	*18·92*	6·41	*14·12*	4·48	*9·88*	4·80	*10·59*	5·13	*11·29*	5·45	12	5·76	*12·71*
8·62	19	6·43	*14·17*	4·50	*9·92*	4·82	*10·63*	5·15	*11·34*	5·47	*12·05*	5·78	*12·76*
8·69	*19·15*	6·48	*14·29*	4·54	10	4·86	*10·71*	5·19	*11·43*	5·51	*12·14*	5·83	*12·86*
8·72	*19·20*	6·50	*14·33*	4·55	*10·04*	4·87	*10·73*	5·20	*11·46*	5·52	*12·17*	5·85	*12·90*
8·79	*19·36*	6·55	*14·44*	4·59	*10·11*	4·92	*10·83*	5·24	*11·55*	5·57	*12·28*	5·90	13
8·83	*19·57*	6·58	*14·50*	4·61	*10·15*	4·94	*10·89*	5·27	*11·60*	5·60	*12·34*	5·93	*13·07*
8·92	*19·65*	6·65	*14·67*	4·66	*10·27*	4·99	11	5·32	*11·73*	5·66	*12·47*	5·99	*13·20*
9	*19·84*	6·71	*14·80*	4·70	*10·35*	5·03	*11·10*	5·37	*11·83*	5·71	*12·58*	6·04	*13·30*
9·07	20	6·76	*14·92*	4·74	*10·44*	5·08	*11·19*	5·42	*11·94*	5·75	*12·68*	6·10	*13·43*
9·13	*20·11*	6·81	15	4·77	*10·50*	5·10	*11·25*	5·45	12	5·79	*12·75*	6·13	*13·50*
9·20	*20·29*	6·86	*15·11*	4·80	*10·58*	5·14	*11·32*	5·48	*12·08*	5·83	*12·85*	6·17	*13·60*
9·31	*20·50*	6·94	*15·29*	4·86	*10·71*	5·21	*11·41*	5·55	*12·23*	5·90	13	6·24	*13·76*
9·39	*20·70*	7	*15·43*	4·90	*10·80*	5·25	*11·56*	5·60	*12·34*	5·95	*13·10*	6·30	*13·88*
9·46	*20·85*	7·06	*15·56*	4·94	*10·89*	5·29	*11·67*	5·64	*12·44*	5·99	*13·22*	6·35	14
9·50	*20·95*	7·07	*15·58*	4·95	*10·90*	5·30	*11·68*	5·65	*12·46*	6	*13·24*	6·36	*14·02*
9·54	21	7·11	*15·67*	4·98	*10·97*	5·33	*11·75*	5·68	*12·53*	6·05	*13·32*	6·40	*14·10*
9·56	*21·06*	7·13	*15·71*	4·99	11	5·34	*11·78*	5·70	*12·57*	6·06	*13·36*	6·42	*14·14*
9·68	*21·35*	7·22	*15·90*	5·06	*11·15*	5·42	*11·93*	5·77	*12·71*	6·14	*13·53*	6·50	*14·33*
9·73	*21·45*	7·26	16	5·08	*11·20*	5·44	12	5·81	*12·80*	6·17	*13·60*	6·53	*14·40*
9·88	*21·78*	7·37	*16·25*	5·16	*11·37*	5·53	*12·19*	5·90	13	6·26	*13·81*	6·64	*14·62*
9·95	*21·93*	7·43	*16·38*	5·20	*11·46*	5·57	*12·28*	5·94	*13·09*	6·32	*13·93*	6·68	*14·73*
9·98	22	7·45	*16·41*	5·21	*11·49*	5·58	*12·31*	5·96	*13·13*	6·33	*13·95*	6·70	*14·77*
10	*22·05*	7·46	*16·45*	5·22	*11·51*	5·59	*12·33*	5·97	*13·17*	6·34	*13·97*	6·71	*14·79*
10·01	*22·08*	7·47	*16·47*	5·23	*11·53*	5·61	*12·35*	5·98	*13·18*	6·35	14	6·72	*14·82*
10·05	*22·17*	7·50	*16·53*	5·24	*11·55*	5·62	*12·37*	6	*13·23*	6·37	*14·06*	6·75	*14·87*
10·13	*22·34*	7·56	*16·67*	5·29	*11·67*	5·67	*12·50*	6·05	*13·33*	6·43	*14·17*	6·81	15
10·25	*22·60*	7·65	*16·87*	5·35	*11·80*	5·74	*12·67*	6·12	*13·49*	6·50	*14·33*	6·87	*15·14*
10·33	*22·78*	7·71	17	5·40	*11·90*	5·78	*12·75*	6·17	*13·60*	6·55	*14·45*	6·94	*15·30*
10·37	*22·90*	7·74	*17·07*	5·42	*11·94*	5·80	*12·80*	6·19	*13·64*	6·57	*14·48*	6·97	*15·35*
10·42	*22·98*	7·77	*17·15*	5·44	*11·99*	5·83	*12·87*	6·22	*13·70*	6·61	*14·56*	7	*15·43*

EQUIVALENT CONSUMPTION, ETC.—*continued.*

Output from Electric Generator corresponding to Engine Consumptions (of Stated Efficiencies) per I.H.P.H. stated in the Columns on the right of this.				Consumption per Indicated Horse-Power Hour. Combined Efficiency of Engine and Generator.									
Consumption per K.W.H. Output.		Consumption per E.H.P.H.		70 per cent.		75 per cent.		80 per cent.		85 per cent.		90 per cent.	
Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*
10·44	23	7·78	17·16	5·45	12·01	5·84	12·87	6·23	13·73	6·62	14·58	7·01	15·44
10·50	23·15	7·83	17·26	5·48	12·08	5·87	12·93	6·26	13·80	6·65	14·65	7·04	15·51
10·53	23·23	7·86	17·33	5·51	12·13	5·90	13	6·29	13·87	6·68	14·73	7·07	15·60
10·64	23·46	7·94	17·50	5·56	12·25	5·95	13·12	6·35	14	6·74	14·87	7·14	15·75
10·73	23·64	8	17·64	5·59	12·33	5·99	13·20	6·39	14·09	6·80	14·98	7·20	15·86
10·74	23·66	8·01	17·65	5·60	12·35	6	13·23	6·40	14·12	6·81	15	7·21	15·88
10·81	23·83	8·06	17·78	5·65	12·44	6·04	13·33	6·45	14·22	6·86	15·11	7·26	16
10·88	24	8·12	17·90	5·68	12·53	6·09	13·43	6·49	14·32	6·90	15·22	7·30	16·11
10·90	24·03	8·13	17·93	5·69	12·55	6·10	13·45	6·50	14·33	6·91	15·24	7·32	16·14
10·93	24·13	8·16	18	5·72	12·60	6·12	13·50	6·53	14·40	6·94	15·30	7·35	16·20
11	24·25	8·20	18·08	5·74	12·65	6·15	13·56	6·56	14·46	6·97	15·36	7·37	16·22
11·28	24·89	8·42	18·57	5·89	13	6·32	13·93	6·74	14·86	7·16	15·79	7·58	16·71
11·34	25	8·45	18·65	5·92	13·05	6·34	13·99	6·77	14·92	7·19	15·85	7·61	16·78
11·35	25·02	8·46	18·67	5·93	13·07	6·35	14	6·78	14·93	7·20	15·87	7·62	16·80
11·37	25·06	8·48	18·71	5·94	13·10	6·36	14·02	6·79	14·96	7·21	15·90	7·63	16·83
11·39	25·13	8·50	18·75	5·95	13·12	6·37	14·06	6·81	15	7·23	15·94	7·65	16·87
11·43	25·23	8·54	18·84	5·98	13·18	6·41	14·12	6·80	15·06	7·26	16	7·68	16·94
11·48	25·32	8·56	18·88	5·99	13·22	6·42	14·17	6·86	15·11	7·28	16·06	7·71	17
11·50	25·36	8·58	18·90	6	13·23	6·43	14·18	6·86	15·12	7·28	16·06	7·72	17·02
11·54	25·47	8·62	19	6·03	13·30	6·47	14·25	6·90	15·20	7·33	16·15	7·75	17·10
11·62	25·63	8·67	19·11	6·07	13·38	6·50	14·33	6·93	15·28	7·37	16·21	7·80	17·20
11·79	26	8·78	19·39	6·15	13·58	6·60	14·55	7·04	15·52	7·47	16·49	7·92	17·46
12	26·45	8·95	19·70	6·26	13·80	6·71	14·78	7·16	15·79	7·60	16·76	8·05	17·75
12·17	26·81	9·07	20	6·35	14	6·81	15	7·26	16	7·71	17	8·16	18
12·24	27	9·13	20·14	6·39	14·10	6·85	15·11	7·31	16·11	7·76	17·12	8·22	18·13
12·50	27·55	9·33	20·58	6·53	14·40	7	15·43	7·46	16·40	7·93	17·60	8·40	18·52
12·70	28	9·47	20·88	6·63	14·62	7·10	15·67	7·57	16·71	8·05	17·75	8·53	18·80
12·74	28·10	9·50	20·94	6·65	14·66	7·12	15·70	7·60	16·76	8·07	17·78	8·55	18·85
12·76	28·15	9·52	21	6·67	14·70	7·14	15·75	7·62	16·80	8·10	17·85	8·57	18·90
12·84	28·30	9·56	21·11	6·70	14·78	7·18	15·83	7·65	16·89	8·14	17·94	8·62	19
12·87	28·39	9·60	21·18	6·72	14·82	7·20	15·88	7·68	16·94	8·17	18	8·64	19·06
12·93	28·48	9·63	21·25	6·74	14·87	7·23	15·94	7·71	17	8·19	18·06	8·67	19·12

EQUIVALENT CONSUMPTIONS, ETC.—*continued.*

Output from Electric Generator corresponding to Engine Consumptions (of Stated Efficiencies) per I.H.P.H. stated in the Columns on the right of this.				Consumption per Indicated Horse-Power Hour. Combined Efficiency of Engine and Generator.									
Consumption per K.W.H. Output.		Consumption per E.H.P.H.		70 per cent.		75 per cent.		80 per cent.		85 per cent.		90 per cent.	
Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*
12·96	*28·60*	9·67	*21·33*	6·77	*14·93*	7·26	**16**	7·74	*17·07*	8·22	*18·13*	8·71	*19·20*
13	*28·66*	9·69	*21·37*	6·78	*14·9*	7·27	*16·04*	7·75	*17·10*	8·23	*18·16*	8·72	*19·22*
13·02	*28·72*	9·72	*21·43*	6·81	**15**	7·28	*16·07*	7·77	*17·14*	8·26	*18·21*	8·75	*19·29*
13·14	**29**	9·82	*21·63*	6·97	*15·14*	7·36	*16·22*	7·85	*17·31*	8·34	*18·39*	8·83	*19·47*
13·37	*29·49*	9·97	**22**	6·98	*15·40*	7·48	*16·50*	7·98	*17·60*	8·47	*18·70*	8·98	*19·80*
13·42	*29·60*	**10**	*22·05*	**7**	*15·43*	7·50	*16·54*	**8**	*17·64*	8·50	*18·73*	**9**	*19·84*
13·51	*29·79*	10·07	*22·22*	7·05	*15·56*	7·57	*16·67*	8·06	*17·78*	8·57	*18·89*	9·08	**20**
13·59	*29·96*	10·13	*22·35*	7·10	*15·65*	7·60	*16·76*	8·11	*17·88*	8·62	**19**	9·11	*20·12*
13·62	**30**	10·15	*22·38*	7·11	*15·67*	7·61	*16·78*	8·12	*17·90*	8·63	*19·02*	9·14	*20·14*
13·67	*30·2*	10·20	*22·50*	7·16	*15·75*	7·65	*16·87*	8·17	**18**	8·67	*19·12*	9·18	*20·25*
13·77	*30·4*	10·28	*22·67*	7·20	*15·87*	7·71	**17**	8·23	*18·13*	8·74	*19·27*	9·25	*20·40*
13·88	*30·6*	10·36	*22·86*	7·26	**16**	7·76	*17·14*	8·29	*18·29*	8·81	*19·43*	9·32	*20·57*
13·97	*30·8*	10·42	**23**	7·30	*16·10*	7·82	*17·25*	8·34	*18·40*	8·86	*19·55*	9·38	*20·70*
14	*30·9*	10·44	*23·04*	7·31	*16·12*	7·83	*17·27*	8·35	*18·42*	8·87	*19·56*	9·40	*20·74*
14·06	**31**	10·49	*23·13*	7·34	*16·19*	7·86	*17·34*	8·39	*18·50*	8·91	*19·66*	9·44	*20·81*
14·07	*31·0*	10·50	*23·15*	7·35	*16·21*	7·87	*17·36*	8·40	*18·52*	8·92	*19·68*	9·45	*20·83*
14·20	*31·3*	10·56	*23·33*	7·41	*16·33*	7·93	*17·50*	8·46	*18·67*	8·99	*19·83*	9·52	**21**
14·25	*31·4*	10·62	*23·42*	7·43	*16·39*	7·97	*17·58*	8·5	*18·73*	9·03	*19·92*	9·56	*21·08*
14·30	*31·5*	10·67	*23·53*	7·47	*16·47*	8·01	*17·65*	8·54	*18·83*	9·07	**20**	9·60	*21·18*
14·38	*31·7*	10·72	*23·65*	7·50	*16·53*	8·04	*17·73*	8·57	*18·89*	9·12	*20·11*	9·65	*21·28*
14·44	*31·8*	10·78	*23·76*	7·54	*16·62*	8·08	*17·81*	8·62	**19**	9·15	*20·19*	9·70	*21·37*
14·51	**32**	10·82	*23·87*	7·58	*16·71*	8·13	*17·90*	8·66	*19·10*	9·21	*20·29*	9·75	*21·45*
14·58	*32·2*	10·88	**24**	7·62	*16·80*	8·17	**18**	8·71	*19·20*	9·25	*20·40*	9·80	*21·60*
14·75	*32·5*	**11**	*24·25*	7·70	*16·98*	8·25	*18·19*	8·80	*19·41*	9·35	*20·61*	9·90	*21·82*
14·77	*32·5*	11·02	*24·29*	7·71	**17**	8·26	*18·21*	8·81	*19·43*	9·37	*20·64*	9·92	*21·86*
14·85	*32·8*	11·08	*24·44*	7·75	*17·11*	8·31	*18·33*	8·86	*19·56*	9·42	*20·78*	9·97	**22**
14·91	*32·9*	11·12	*24·52*	7·78	*17·15*	8·33	*18·38*	8·89	*19·63*	9·44	*20·82*	**10**	*22·07*
14·97	**33**	11·17	*24·62*	7·81	*17·23*	8·37	*18·46*	8·93	*19·69*	9·49	*20·92*	10·04	*22·16*
15	*33·1*	11·19	*24·67*	7·83	*17·26*	8·39	*18·50*	8·95	*19·73*	9·51	*20·89*	10·07	*22·20*
15·04	*33·1*	11·21	*24·71*	7·85	*17·29*	8·40	*18·53*	8·96	*19·76*	9·52	**21**	10·08	*22·25*
15·08	*33·3*	11·25	*24·80*	7·87	*17·35*	8·44	*18·62*	**9**	*19·84*	9·57	*21·11*	10·13	*22·31*
15·21	*33·5*	11·33	**25**	7·93	*17·50*	8·50	*18·75*	9·07	**20**	9·63	*21·25*	10·21	*22·50*

EQUIVALENT CONSUMPTIONS, ETC.—*continued.*

Output from Electric Generator corresponding to Engine Consumptions (of Stated Efficiencies) per I.H.P.H. stated in the Columns on the right of this.				Consumption per Indicated Horse-Power Hour. Combined Efficiency of Engine and Generator.									
Consumption per K.W.H. Output.		Consumption per E.H.P.H.		70 per cent.		75 per cent.		80 per cent.		85 per cent.		90 per cent.	
Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*
15·30	*33·7*	11·43	*25·22*	8	*17·64*	8·57	*18·89*	9·14	*20·16*	9·72	*21·44*	10·28	*22·27*
15·40	*33·9*	11·48	*25·33*	8·04	*17·73*	8·62	**19**	9·20	*20·27*	9·76	*21·53*	10·34	*22·80*
15·42	**34**	11·50	*25·35*	8·05	*17·74*	8·63	*19·01*	9·21	*20·28*	9·77	*21·55*	10·35	*22·82*
15·44	*34·1*	11·51	*25·36*	8·05	*17·75*	8·63	*19·02*	9·25	*20·29*	9·77	*21·56*	10·36	*22·83*
15·54	*34·3*	11·58	*25·56*	8·11	*17·89*	8·69	*19·17*	9·27	*20·44*	9·85	*21·72*	10·44	**23**
15·63	*34·5*	11·66	*25·71*	8·17	**18**	8·75	*19·29*	9·33	*20·57*	9·93	*21·86*	10·50	*23·14*
15·73	*34·7*	11·74	*25·88*	8·22	*18·12*	8·80	*19·41*	9·40	*20·71*	9·97	**22**	10·56	*23·29*
15·78	*34·8*	11·76	*25·94*	8·24	*18·17*	8·82	*19·44*	9·42	*20·76*	10	*22·05*	10·60	*23·36*
15·80	*34·8*	11·78	**26**	8·25	*18·20*	8·84	*19·50*	9·43	*20·80*	10·02	*22·10*	10·61	*23·40*
15·87	**35**	11·83	*26·11*	8·39	*18·28*	8·89	*19·58*	9·47	*20·89*	10·06	*22·19*	10·65	*23·50*
15·96	*35·2*	11·90	*26·25*	8·33	*18·37*	8·93	*19·69*	9·52	**21**	10·11	*22·31*	10·71	*23·62*
16	*35·3*	11·93	*26·32*	8·35	*18·41*	8·95	*19·73*	9·55	*21·06*	10·14	*22·37*	10·74	*23·69*
16·20	*35·7*	12·09	*26·67*	8·46	*18·67*	9·07	**20**	9·66	*21·33*	10·27	*22·67*	10·88	**24**
16·27	*35·9*	12·14	*26·77*	8·50	*18·73*	9·11	*20·08*	9·72	*21·40*	10·32	*32·78*	10·93	*24·10*
16·33	**36**	12·18	*26·86*	8·52	*18·80*	9·14	*20·14*	9·75	*21·48*	10·35	*22·83*	10·95	*24·12*
16·39	*36·1*	12·23	*26·97*	8·56	*18·87*	9·17	*20·20*	9·78	*21·56*	10·39	*22·90*	11	*24·23*
16·40	*36·2*	12·25	**27**	8·57	*18·90*	9·19	*20·25*	9·79	*21·60*	10·40	*22·95*	11·01	*24·30*
16·45	*36·3*	12·27	*27·06*	8·59	*18·94*	9·21	*20·29*	9·82	*21·65*	10·42	**23**	11·03	*24·35*
16·50	*36·4*	12·29	*27·14*	8·62	**19**	9·24	*20·36*	9·84	*21·71*	10·46	*23·07*	11·07	*24·43*
16·55	*36·5*	12·36	*27·28*	8·65	*19·08*	9·27	*20·43*	9·87	*21·77*	10·50	*23·15*	11·12	*24·54*
16·72	*36·9*	12·47	*27·50*	8·73	*19·25*	9·36	*20·62*	9·97	**22**	10·60	*23·37*	11·22	*24·75*
16·76	*36·9*	12·50	*27·55*	8·75	*19·30*	9·37	*20·65*	10	*22·05*	10·63	*23·44*	11·23	*24·81*
16·78	**37**	12·52	*27·60*	8·76	*19·32*	9·39	*20·70*	10·01	*22·08*	10·64	*23·46*	11·25	*24·84*
16·89	*37·2*	12·59	*27·78*	8·82	*19·44*	9·44	*20·83*	10·07	*22·22*	10·70	*23·61*	11·33	**25**
16·98	*37·4*	12·67	*27·94*	8·86	*19·55*	9·50	*20·94*	10·13	*22·33*	10·77	*23·76*	11·40	*25·15*
17	*37·5*	12·70	**28**	8·88	*19·60*	9·53	**21**	10·15	*22·40*	10·78	*23·80*	11·42	*25·20*
17·14	*37·7*	12·78	*28·18*	8·94	*19·70*	9·58	*21·12*	10·22	*22·56*	10·86	*23·97*	11·50	*25·36*
17·16	*37·8*	12·80	*28·23*	8·96	*19·76*	9·60	*21·18*	10·23	*22·59*	10·87	**24**	11·53	*25·41*
17·24	**38**	12·85	*28·35*	9	*19·84*	9·65	*21·26*	10·28	*22·68*	10·98	*24·10*	11·57	*25·51*
17·36	*38·3*	12·94	*28·55*	9·06	*19·97*	9·70	*21·39*	10·35	*22·84*	11	*24·25*	11·65	*25·68*
17·37	*38·3*	12·95	*28·57*	9·07	**20**	9·72	*21·43*	10·37	*22·86*	11·02	*24·29*	11·68	*25·71*
16·43	*38·4*	13	*28·66*	9·10	*20·07*	9·75	*21·50*	10·40	*22·93*	11·05	*24·40*	11·70	*25·80*

EQUIVALENT CONSUMPTIONS, ETC.—*continued.*

Output from Electric Generator corresponding to Engine Consumptions (of Stated Efficiencies) per I.H.P.H. stated in the Columns on the right of this.				Consumption per Indicated Horse-Power Hour. Combined Efficiency of Engine and Generator.									
Consumption per K W.H. Output.		Consumption per E.H.P.H.		70 per cent.		75 per cent.		80 per cent.		85 per cent.		90 per cent.	
Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*
17·47	*38·5*	13·04	*28·75*	9·13	*20·12*	9·78	*21·56*	10·42	**23**	11·08	*24·44*	11·73	*25·87*
17·57	*38·7*	13·10	*28·89*	9·16	*20·22*	9·84	*21·67*	10·47	*23 11*	11·13	*24·56*	11·78	**26**
17·60	*38·8*	13·13	**29**	9·19	*20 28*	9·85	*21·71*	10·50	*23·15*	11·16	*24·62*	11·82	*26·08*
17·64	*38·9*	13·15	*29·00*	9·21	*20·30*	9·86	*21·75*		*23·20*	11·17	*24·65*	11·83	*26·10*
17·68	**39**	13·18	*29·09*	9·24	*20·37*	9·91	*21·82*	10·55	*23·27*	11·20	*24·73*	11·87	*26·18*
17·83	*39·3*	13·29	*29·33*	9·31	*20·53*	9·98	**22**	10·64	*23·47*	11·30	*24·93*	11·96	*26·40*
17·88	*39·4*	13·30	*29·41*	9·34	*20·59*	9·99	*22·06*	10·66	*23·53*	11·33	**25**	**12**	*26·45*
18	*39·7*	13·43	*29·62*	9·40	*20·72*	10·07	*22·23*	10·74	*23·70*	11·42	*25·20*	12·09	*26·70*
18·14	**40**	13·54	*29·84*	9·48	*20·88*	10·14	*22·38*	10·83	*23·87*	11·49	*25·36*	12·17	*26·86*
18·20	*40·2*	13·56	*29·91*	9·50	*20·95*	10·17	*22·45*	10·85	*23·91*	11·53	*25·45*	12·20	*26·92*
18·21	*40·2*	13·60	**30**	9·52	**21**	10·20	*22·50*	10·88	**24**	11·56	*25·50*	12·24	**27**
18·46	*40·7*	13·76	*30·4*	9·63	*21·26*	10·32	*22·76*	**11**	*24·25*	11·69	*25·80*	12·28	*27·32*
18·59	**41**	13·87	*30·6*	9·71	*21·41*	10·40	*22 94*	11·10	*24·47*	11·79	*25·99*	12·47	*27·53*
18·60	*41·0*	13·88	*30·6*	9·72	*21·41*	10·41	*22·94*	11·11	*24 47*	11·80	**26**	12·47	*27·53*
18·65	*41·1*	13·91	*30·7*	9·74	*21 47*	10·43	**23**	11·12	*24·53*	11·82	*26·07*	12·50	*27·60*
18·77	*41·4*	**14**	*30·9*	9·80	*21·60*	10·50	*23·15*	11·20	*24·71*	11·90	*26·26*	12·60	*27·80*
18·83	*41·5*	14·06	**31**	9·84	*21·70*	10·54	*23·25*	11·24	*24·80*	11·94	*26·35*	12·65	*27·90*
18·90	*41·7*	14·10	*31·1*	9·87	*21·78*	10·57	*23·33*	11·29	*24·89*	11·98	*26·44*	12·70	**28**
18·95	*41·8*	14·14	*31·2*	9·90	*21·85*	10·60	*23·40*	11·30	*24·93*	**12**	*26·45*	12·72	*28·04*
19	*41·9*	14·17	*31·2*	9·93	*21·87*	10·64	*23·44*	11·33	**25**	12·03	*26·56*	12·76	*28·12*
19·04	**42**	14·20	*31·3*	9·95	*21·93*	10·65	*23·49*	11·37	*25·07*	12·08	*26·63*	12·78	*28·20*
19·11	*42·1*	14·26	*31·4*	9·98	**22**	10·68	*23·57*	11·40	*25·14*	12·10	*26·71*	12·83	*28·29*
19·17	*42·3*	14·30	*31·6*	**10**	*22·05*	10·72	*23·67*	11·44	*25·23*	12·15	*26·80*	12·87	*28·40*
19·32	*42·6*	14·40	*31·8*	10·07	*22·23*	10·81	*23·83*	11·52	*25·41*	12·23	**27**	12·96	*28·59*
19·37	*42·7*	14·45	*31·9*	10·11	*22·31*	10·83	*23·89*	11·55	*25·58*	12·27	*27·10*	**13**	*28·66*
19·48	*42·9*	14·50	**32**	10·15	*22·40*	10·89	**24**	11·60	*25·60*	12·33	*27·20*	13·06	*28·80*
19·51	**43**	14·54	*32·1*	10·18	*22·45*	10·92	*24·06*	11·64	*25·66*	12·36	*27·27*	13·10	*28·87*
19·60	*43·2*	14·60	*32·2*	10·23	*22·55*	10·95	*24·17*	11·68	*25·78*	12·41	*27·39*	13·15	**29**
19·66	*43·3*	14·67	*32·4*	10·26	*22·62*	**11**	*24·25*	11·73	*25·89*	12·47	*27·50*	13·20	*29·11*
19·77	*43·6*	14·73	*32 5*	10·33	*22·75*	11·04	*24·37*	11·78	**26**	12·53	*27·62*	13·26	*29·25*
19·95	**44**	14·89	*32·8*	10·41	*22·98*	11·16	*24·62*	11·90	*26·26*	12·65	*27·90*	13·39	*29·54*
19·97	*44·1*	14·90	*32·9*	10·43	**23**	11·17	*24·64*	11·91	*26·29*	12·66	*27·93*	13·41	*29·57*
20	*44·1*	14·92	*32·9*	10·45	*23·04*	11·19	*24·68*	11·92	*26·32*	12·68	*27·98*	13·43	*29·62*

Equivalent Consumptions, etc.—*continued.*

Output from Electric Generator corresponding to Engine Consumptions (of Stated Efficiencies) per I.H.P.H. stated in the Columns on the right of this.				Consumption per Indicated Horse-Power Hour. Combined Efficiency of Engine and Generator.									
Consumption per K.W.H. Output.		Consumption per E.H.P.H.		70 per cent.		75 per cent.		80 per cent.		85 per cent.		90 per cent.	
Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*	Kgs.	*Pounds.*
20·03	*44·2*	14·94	**33**	10·46	*23·06*	11·20	*24·71*	11·93	*26·35*	12·70	**28**	13·44	*29·65*
20·07	*44·2*	14·97	*33·*	10·47	*23·10*	11·22	*24·75*	11·97	*26·40*	12·72	*28·05*	13·46	*29·70*
20·10	*44·3*	**15**	*33·1*	10·50	*23·15*	11·24	*24·80*	**12**	*26·45*	12·75	*28·12*	13·50	*29·80*
20·25	*44·7*	15·11	*33·3*	10·57	*23·33*	11·33	**25**	12·08	*26·67*	12·85	*28·33*	13·61	**30**
20·40	**45**	15·22	*33·6*	10·65	*23·50*	11·41	*25·18*	12·18	*26·86*	12·94	*28·53*	13·70	*30·2*
20·52	*45·2*	15·31	*33·7*	10·71	*23·62*	11·47	*25·31*	12·24	**27**	12·98	*28·64*	13·77	*30·4*
20·60	*45·4*	15·35	*33·9*	10·74	*23·70*	11·50	*25·36*	12·27	*27·07*	13·03	*28·66*	13·80	*30·5*
20·67	*45·5*	15·42	**34**	10·78	*23·80*	11·56	*25·50*	12·33	*27·20*	13·10	*28·90*	13·87	*30·6*
20·72	*45·7*	15·46	*34·1*	10·83	*23·88*	11·60	*25·59*	12·38	*27·29*	13·15	**29**	13·92	*30·7*
20·82	*45·9*	15·55	*34·3*	10·87	*23·98*	11·65	*25·71*	12·42	*27·43*	13·21	*29·14*	13·99	*30·9*
20·85	**46**	15·56	*34·3*	10·88	**24**	11·66	*25·72*	12·43	*27·43*	13·22	*29·15*	**14**	*30·9*
20·86	,,	15·57	*34·3*	10·89	*24·02*	11·67	*25·74*	12·44	*27·45*	13·23	*29·17*	14·01	*30·9*
20·94	*46·2*	15·60	*34·4*	10·93	24·11	11·70	*25·83*	12·50	*27·56*	13·28	*29·28*	14·05	**31**
21	*46·3*	15·65	*34·5*	**11**	*24·23*	11·73	*25·89*	12·51	*27·59*	13·30	*29·33*	14·08	*31·1*
21·03	*46·5*	15·72	*34·7*	11·01	*24·27*	11·78	**26**	12·57	*27·73*	13·37	*29·47*	14·14	*31·2*
21·28	*46·9*	15·87	**35**	11·11	*24·50*	11·88	*26·25*	12·70	**28**	13·49	*29·75*	14·27	*31·5*
21·32	**47**	15·90	*35·1*	11·13	*24·54*	11·92	*26·30*	12·72	*28·05*	13·51	*29·80*	14·30	*31·6*
21·33	,,	**16**	*35·3*	11·20	*24·69*	**12**	*26·40*	12·80	*28·22*	13·59	*29·97*	14·39	*31·7*
21·45	*47·2*	16·07	*35·3*	11·21	*24·71*	12·1	*26·47*	12·81	*28·24*	13·60	**30**	14·4	*31·8*
21·62	*47·7*	16·12	*35·6*	11·28	*24·89*	12·10	*26·67*	12·90	*28·44*	13·70	*30·2*	14·51	**32**
21·72	*47·9*	16·20	*35·7*	11·34	**25**	12·13	*26·79*	12·95	*28·57*	13·78	*30·4*	14·57	*32·1*
21·77	**48**	16·24	*35·8*	11·35	*25·07*	12·17	*26·86*	12·98	*28·65*	13·80	*30·4*	14·61	*32·2*
21·80	*48·1*	16·26	*35·9*	11·38	*25·14*	12·20	*26·92*	**13**	*28·66*	13·82	*30·5*	14·64	*32·3*
21·88	*48·3*	16·33	**36**	11·42	*25·20*	12·24	*27*	13·06	*28·80*	13·87	*30·6*	14·69	*32·4*
22	*48·5*	16·40	*36·2*	11·47	*25·30*	12·29	*27·11*	13·12	*28·93*	13·94	*30·8*	14·75	*32·6*
22·04	*48·6*	16·44	*36·2*	11·51	*25·37*	12·32	*27·19*	13·15	**29**	13·97	*30·8*	14·80	*32·6*
22·08	*48·7*	16·48	*36·3*	11·53	*25·40*	12·36	*27·28*	13·18	*29·10*	**14**	*30·9*	14·83	*32·7*
22·20	*48·9*	16·55	*36·5*	11·57	*25·53*	12·40	*27·35*	13·21	*29·18*	14·05	**31**	14·88	*32·8*
22·23	**49**	16·58	*36·6*	11·60	*25·59*	12·43	*27·41*	13·26	*29·24*	14·09	*31·1*	14·92	*32·9*
22·30	*49·1*	16·64	*36·7*	11·64	*25·67*	12·46	*27·50*	13·30	*29·33*	14·13	*31·2*	14·97	**33**
22·33	*49·2*	16·67	*36·8*	11·66	*25·72*	12·50	*27·55*	13·33	*29·40*	14·15	*31·2*	**15**	*33·1*
22·50	*49·6*	16·78	**37**	11·75	*25·90*	12·58	*27·75*	13·42	*29·60*	14·27	*31·4*	15·11	*33·3*
22·58	*49·8*	16·84	*37·1*	11·80	**26**	12·64	*27·86*	13·47	*29·71*	14·31	*31·6*	15·16	*33·4*

TABLE CLI.—VACUA.

Equivalent Values based on the Metric Atmosphere, *i.e.*, 1 Kg. per Sq. Cm. = 1 Metric Atmosphere.

Per cent. of perfect Vacuum.	Reading of Mercury Vacuum Gauge.		Absolute Pressure in Condenser.		
	Mm.	Inches.	Kgs. per Sq. Cm.	Lbs. per Sq. Inch.	English Atmosphere.
100	735	29·0	0·0	0·0	0·0
99·5	732	28·8	0·005	0·071	0·0048
99	728	28·7	0·01	0·142	0·0097
98·5	724	28·5	0·015	0·213	0·0145
98	721	28·4	0·02	0·284	0·0194
97·5	717	28·2	0·025	0·356	0·0242
97	713	28·1	0·03	0·427	0·0290
96·5	710	27·9	0·035	0·498	0·0339
96	706	27·8	0·04	0·569	0·0387
95·5	702	27·6	0·045	0·640	0·0435
95	699	27·5	0·05	0·711	0·0484
94	691	27·2	0·06	0·853	0·0581
93	684	26·9	0·07	0·996	0·0677
92	677	26·6	0·08	1·138	0·0774
91	669	26·3	0·09	1·280	0·0871
90	662	26·1	0·10	1·422	0·0968
88	647	25·5	0·12	1·707	0·1161
86	632	24·9	0·14	1·991	0·1355
84	618	24·3	0·16	2·28	0·1548
82	603	23·7	0·18	2·56	0·1742
80	588	23·2	0·20	2·84	0·1936
75	552	21·7	0·25	3·55	0·242
70	515	20·3	0·3	4·27	0·290
65	478	18·8	0·35	4·98	0·339
60	441	17·4	0·4	5·69	0·387
55	404	15·9	0·45	6·40	0·435
50	368	14·5	0·5	7·11	0·484

TABLE CLII.—VACUA.

Equivalent Values based on the English Atmosphere, *i.e.*, 30 inches or 760 mm. of Mercury = 1 English Atmosphere.

Per cent. of perfect Vacuum.	Reading of Mercury Vacuum Gauge.		Absolute Pressure in Condenser.		
	Mm.	Inches.	English Atmosphere.	Kgs. per Sq. Cm.	Lbs. per Sq. Inch.
100	760	30	0	0	0
99·5	756	29·8	0·005	0·0052	0·0735
99	752	29·7	0·01	0·0103	0·147
98·5	749	29·5	0·015	0·0156	0·220
98	744	29·4	0·02	0·0207	0·294
97·5	741	29·2	0·025	0·0258	0·368
97	737	29·1	0·03	0·0310	0·441
96·5	733	28·9	0·035	0·0362	0·514
96	730	28·8	0·04	0·0413	0·588
95·5	726	28·6	0·045	0·0465	0·661
95	722	28·5	0·05	0·0517	0·735
94	714	28·2	0·06	0·0620	0·882
93	707	27·9	0·07	0·0723	1·029
92	699	27·6	0·08	0·0827	1·176
91	692	27·3	0·09	0·0930	1·323
90	684	27·0	0·10	0·1033	1·470
88	669	26·4	0·12	0·1240	1·763
86	654	25·8	0·14	0·1447	2·06
84	638	25·2	0·16	0·1653	2·35
82	623	24·6	0·18	0·1860	2·65
80	608	24·0	0·20	0·207	2·94
75	570	22·5	0·25	0·258	3·67
70	532	21·0	0·30	0·310	4·41
65	494	19·5	0·35	0·362	5·14
60	456	18·0	0·40	0·413	5·88
55	418	16·5	0·45	0·465	6·61
50	380	15·0	0·60	0·517	7·35

760 mm. = 29·9 inches. 30 inches = 762 millimetres.

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